REPUBLIC OF TURKEY

INSTITUTE OF HEALTH SCIENCES

SKELETAL AND DENTOALVEOLAR EFFECTS OF FORSUS™ FATIGUE RESISTANT DEVICE IN CLASS II DIVISION 1 PATIENTS

SERKAN SAĞIR

DOCTORATE THESIS

DEPARTMENT OF ORTHODONTICS

SUPERVISOR

Associate Prof. Dr. Toros ALCAN

ISTANBUL-2010

TEZ ONAYI

Kurum : Marmara Üniversitesi Sağlık Bilimleri Enstitüsü

Programın seviyesi : Yüksek Lisans ( ) Doktora (✓)

Anabilim Dalı: Ortodonti

Tez Sahibi : Serkan Sağır

Tez Başlığı : 'Skeletal and Dentoalveolar Effects of Forsus Fatigue Resistant Device in Class II Division 1 Patients'

Sınav Yeri : M.Ü. Ortodonti Anabilim Dalı

Sınav Tarihi : 23.06.2010

Tez tarafımızdan okunmuş, kapsam ve kalite yönünden Yüksek Lisans/Doktora Tezi olarak kabul edilmiştir.

Danışman (Unvan, Adı, Soyadı)	Kurumu	İmza
Doç. Dr. Toros Alcan	M.Ü. Ortodonti A.D	

Sınav Jüri Üyeleri (Unvan, Adı, Soyadı)

Prof. Dr. Serdar Uğurlu	Gaziantep Üniv.	
Prof. Dr. Nazan Küçükkeleş	Marmara Üh	
Yrd. Doç. Dr. Didem Malkoç Gül	Yeditepe Üniv.	
Prof. Dr. Sibel Biren	Marmara Üh.	

Yukarıdaki jüri kararı Enstitü yönetim Kurulu'nun 23/06/2010 tarih ve 9. sayılı kararı ile onaylanmıştır.

Prof.Dr. Nihat GENÇOĞLU

Sağlık Bilimleri Enstitüsü Müdürü

BEYAN

Bu tez çalışmasının kendi çalışmam olduğunu, tezin planlanmasından yazımına kadar bütün aşamalarda etik dışı davranışımın olmadığını, bu tezdeki bütün bilgileri akademik ve etik kurallar içinde elde ettiğimi, bu tez çalışmasıyla elde edilmeyen bütün bilgi ve yorumlara kaynak gösterdiğimi ve bu kaynakları da kaynaklar listesine aldığımı, yine bu tezin çalışılması ve yazımı sırasında patent ve telif haklarını ihlal edici bir davranışımın olmadığını beyan ederim.

TARİH

SERKAN SAĞIR

I) ACKNOWLEDGEMENT

First and foremost, I would like to thank my thesis supervisor and our lecturer Assoc. Prof. Dr. Toros Alcan, for all his help, his care, understanding and optimism during the preparation of my thesis. Above all, I thank him for his trust on me, and giving the opportunity to put into practice most of the things I wanted to do during both clinical and writing phase.

I would like to thank the head of our department and our lecturer Prof. Dr. Sibel Biren, for her positiveness, compassion and giving me the feeling of being trustworthy. Prof. Dr. Nejat Erverdi for all his effort to found our worldwide department, Prof. Dr. Nazan Küçükkeleş not only for all her effort and support for this thesis study; but also her listening and giving me the courage of my convictions, Prof. Dr. Ahu Acar for her sympathy and helpfulness whenever I needed, Assoc. Prof. Dr. Banu Çakırer for her all understanding and support throughout my education. I also thank Assoc. Prof. Dr. Arzu Arı Demirkaya for all her effort on me beginning from my undergraduate education and encouraging me to apply this department when I was a student.

I have been very glad to be here and I would like to show my appreciation to all my lecturers for giving me the opportunity to be a part of this department.

I would like to express my thankfullness to my family, for their endless substantial support and care throughout my life.

I thank all my friends and collegues in our department for their company and cooperation, and our technicians and staff for their complimentary help throughout my education. Especially, I thank Dt. Selçuk Yılmaz for his friendship and hard times we shared together.

Finally, I must thank Dt. R. Burcu Nur, for her constant encouraging, emotional support and help during the preparation of my thesis.

Serkan Sağır

II) CONTENTS

I) Acknowledgement.....II

II) Contents.....III

III) Abbreviations and Symbols.....VII

IV) List of Tables.....IX

V) List of Pictures.....X

VI) List of Figures.....XII

1. Summary.....1

2. Özet.....3

3. Introduction and Aim.....5

4. Literature Review.....7

4.1 Epidemiology.....7

4.2. Etiology.....11

4.2.1. Hereditary, or Genetic Factors.....11

4.2.2. Environmental Factors.....14

4.3. Dental and Skeletal Characteristics of Class II Malocclusion.....15

4.3.1. Dental Characteristics of Class II Malocclusion.....16

4.3.1.1. Dental arch Shape and Characteristics.....19

4.3.2. Skeletal Characteristics of Class II Malocclusion.....22

4.3.3. Soft-tissue Characteristics of Class II Division 1 Malocclusion.....29

4.3.4. Perioral Functional Characteristics of Class II Division 1 Malocclusion...31

4.3.5. Condyle Position in Class II Division 1 Malocclusion.....33

4.4. Growth and Development.....35

4.4.1. The Cranial Vault.....36

4.4.2. The Cranial Base.....36

4.4.3. Maxilla (Nasomaxillary Complex).....38

4.4.4. Mandible.....40

4.5. Treatment Modalities of Class II Division 1 Malocclusions.....46

4.5.1. Treatment Approaches to Dental Class II Malocclusions.....46

4.5.1.1. Extraction vs. Nonextraction Treatment.....46

4.5.2. Treatment Approaches to Skeletal Class II Malocclusions.....47

4.5.2.1. Growth Modification.....47

4.5.2.1.1. Extraoral Force (Headgear) Appliances.....48

4.5.2.1.2. Functional Appliances.....53

4.5.2.1.2.1. How Do Functional Appliances Stimulate the Condylar Growth?.....56

4.5.2.1.2.2. Removable Tooth-borne Functional Appliances.....58

4.5.2.1.2.2.1. Activator.....59

4.5.2.1.2.2.2. Bionator.....59

4.5.2.1.2.2.3. Twin-Block.....60

4.5.2.1.2.3. Removable Tissue-borne Functional Appliances.....61

4.5.2.1.2.4. Fixed Tooth-borne Functional Appliances.....63

4.5.2.1.2.4.1. Herbst Appliance.....64

4.5.2.1.2.4.2. Jasper Jumper.....83

4.5.2.1.2.4.3. Mandibular Protraction Appliance (MPA).....90

4.5.2.1.2.4.4. Eureka Spring.....92

4.5.2.1.2.4.5. Twin Force Bite Corrector.....94

4.5.2.1.2.4.6. Ritto Appliance.....97

4.5.2.1.2.4.7. Mandibular Anterior Repositioning Appliance (MARA)..99

4.5.2.1.2.4.8. Forsus.....102

4.5.2.1.3. Interarch Elastic Traction.....108

4.5.2.2. Dental Camouflage.....110

4.5.2.2.1. Dental Camouflage without Extractions.....111

4.5.2.2.2. Dental Camouflage with Extractions.....112

4.5.2.3. Orthognathic Surgery.....115

4.5.3. Timing of Class II Malocclusion Treatment.....116

4.5.3.1. Timing of Functional Appliance Treatment.....121

4.5.3.1.1. Functional Appliance Treatment as an Alternative to Orthognathic Surgery.....123

5. Subjects and Method.....126

5.1. Subjects.....126

5.1.1. Subjects Selection Criteria.....126

5.2. Method.....130

5.2.1. Characteristics of FFRD.....131

5.2.2. Preparation of the Patients, Application of the Appliance, and Activation/Reactivation.....134

5.2.3. Patient Consent.....152

5.2.4. Cephalometric Evaluation.....152

5.2.4.1. Landmarks Used in Lateral Cephalometric Analysis.....153

5.2.4.2. Planes Used in Lateral Cephalometric Analysis.....155

5.2.4.3. Reference Lines.....155

5.2.4.4. Skeletal Measurements Used in Lateral Cephalometric Analysis.....156

5.2.4.4.1. Angular Skeletal Measurements Used in Lateral Cephalometric Analysis.....156

5.2.4.4.2. Linear Skeletal Measurements Used in Lateral Cephalometric Analysis.....156

5.2.4.5. Dental Measurements Used in Lateral Cephalometric Analysis.....157

5.2.4.5.1. Angular Dental Measurements Used in Lateral Cephalometric Analysis.....157

5.2.4.5.2. Linear Dental Measurements Used in Lateral Cephalometric Analysis.....157

5.2.4.6. Soft-tissue Measurements Used in Lateral Cephalometric Analysis..158

5.2.4.6.1. Angular Soft-tissue Measurements Used in Lateral Cephalometric Analysis.....158

5.2.4.6.2. Linear Soft-tissue Measurements Used in Lateral Cephalometric Analysis.....159

5.2.5. Statistical Method.....169

5.2.5.1. Error of the Method.....169

6. Results.....170

6.1. Method Error Evaluation.....170

6.2. Evaluation of Lateral Cephalograms.....174

6.2.1. Evaluation of Skeletal Changes between T0 and T1.....174

6.2.2. Evaluation of Dental Changes between T0 and T1.....178

6.2.3. Evaluation of Soft-tissue Changes between T0 and T1.....180

6.2.4. Evaluation of Skeletal Changes between T1 and T2.....182

6.2.5. Evaluation of Dental Changes between T1and T2.....185

6.2.6. Evaluation of Soft-tissue Changes between T1 and T2.....187

6.2.7. Comparison of Treatment Changes Between T0-T1 and T1-T2.....189

6.2.7.1. Comparison of Skeletal Treatment Changes Between T0-T1 and T1-T2.....189

6.2.7.2. Comparison of Dental Treatment Changes Between T0-T1 and T1-T2.....192

6.2.7.3. Comparison of Soft-tissue Treatment Changes between T0-T1 and T1-T2.....194

7. Discussion.....196

7.1. Discussion of Aim.....196

7.2. Discussion of Material and Method.....199

7.3. Discussion of Results.....214

7.3.1. Discussion of Skeletal Changes.....214

7.3.1.1. Discussion of Sagittal Skeletal Changes.....214

7.3.1.2. Discussion of Vertical Skeletal Changes.....219

7.3.2. Discussion of Dental Changes.....223

7.3.3. Discussion of Soft-tissue Changes.....232

8. Conclusions.....236

9. References.....238

10. Biography.....268

11. Ethical Committee Confirmation Report.....269

III) ABBREVIATIONS and SYMBOLS

1.	°	: degree
2.	%	: per cent
3.	”	: inch
4.	et al	: and friends
5.	mm	: millimeters
6.	cm	: centimeters
7.	g	: gram
8.	N	: Newton
9.	p	: Probability
10.	SD	: Standard deviation
11.	X	: Mean value
12.	OJ	: Overjet
13.	OB	: Overbite
14.	FJO	: Functional Jaw Orthopedics
15.	EMG	: Electromyographic imaging
16.	MRI	: Magnetic resonance imaging
17.	FRD	: Forsus™ Fatigue Resistant Device
18.	TPA	: Transpalatal Arch
19.	TMJ	: Temporomandibular joint
20.	TMD	: Temporomandibular disorder
21.	LPM	: Lateral pterygoid muscle
22.	EARR	: External apical root resorption
23.	CBJ	: Cantilever Bite Jumper
24.	MPA	: Mandibular Protraction Appliance

25. ES : Eureka Spring

26. TFBC : Twin Force Bite Corrector

27. MARA : Mandibular Anterior Repositioning Appliance

28. FNFS : Forsus™ Nitinol Flat Spring

29. RL : Reference line

30. i.e. : for example

31. etc. : et cetera

32. n : number

IV) LIST of TABLES

Table 1: Sex distribution in study group.

Table 2: Chronological age distribution in study group at T0, T1 and T2.

Table 3: Growth stage distribution in study group at T0, T1 and T2.

Table 4: Evaluation of cephalometric tracing reliability of skeletal measurements by using intraclass correlation coefficient.

Table 5: Evaluation of cephalometric tracing reliability of dental measurements by using intraclass correlation coefficient.

Table 6: Evaluation of cephalometric tracing reliability of soft-tissue measurements by using intraclass correlation coefficient.

Table 7: Statistical evaluation of skeletal changes between T0 and T1.

Table 8: Statistical evaluation of dental changes between T0 and T1.

Table 9: Statistical evaluation of soft-tissue changes between T0 and T1.

Table 10: Statistical evaluation of skeletal changes between T1 and T2.

Table 11: Statistical evaluation of dental changes between T1 and T2.

Table 12: Statistical evaluation of soft-tissue changes between T1 and T2.

Table 13: Comparison of skeletal treatment changes between T0-T1 and T1-T2.

Table 14: Comparison of dental treatment changes between T0-T1 and T1-T2.

Table 15: Comparison of soft-tissue treatment changes between T0-T1 and T1-T2.

V) LIST of PICTURES

Picture 1: Forsus™ Fatigue Resistant Device L-Pin Module Appliance Kit.

Picture 2: Forsus™ Fatigue Resistant Device L-Pin Module.

Picture 3: Right and Left Forsus™ Fatigue Resistant Device L-Pin Modules.

Picture 4: Push Rod Kit.

Picture 5: Usage of Forsus™ Device Gauge to choose appropriate push rod size.

Picture 6: L pin is bent oclusally around headgear tube.

Picture 7: Forsus™ Fatigue Resistant Device L-Pin Module in the mouth.

Picture 8: Occlusal view of the upper arch with Banded Hyrax.

Picture 9: Occlusal view of the upper occlusal view of the lower arch with transpalatal arch.

Picture 10: Occlusal view of the lower arch with lingual arch.

Picture 11: Extraoral photographs of the patient at T0.

Picture 12: Intraoral photographs of the patient at T0.

Picture 13: Extraoral photographs of the patient at T1.

Picture 14: Intraoral photographs of the patient at T1.

Picture 15: Forsus™ Fatigue Resistant Device L-Pin Module in the mouth.

Picture 16: Amount of OJ at T1.

Picture 17: Extraoral photographs of the patient at T2.

Picture 18: Intraoral photographs of the patient at T2.

Picture 19: Extraoral photographs of the patient at T3.

Picture 20: Intraoral photographs of the patient at T3.

Picture 21: TPA embedded into the palatal mucosa as complication.

Picture 22: Lingual arch in an upward position after the removal of the FRD.

VI) LIST of FIGURES

Figure 1: Fishman's 11 skeletal maturity indicator stages.

Figure 2: Average statural growth rate for females and males.

Figure 3: Stages of the study.

Figure 4: Lateral cephalometric radiogram of the patient at T0.

Figure 5: Lateral cephalometric radiogram of the patient at T1.

Figure 6: Superimposition of the lateral cephalometric radiograms taken at T0 and T1.

Figure 7: Lateral cephalometric radiogram of the patient at T2.

Figure 8: Superimposition of the lateral cephalometric radiograms taken at T1 and T2.

Figure 9: Landmarks used in lateral cephalometric analysis.

Figure 10: Planes used in lateral cephalometric analysis.

Figure 11: Reference lines used in lateral cephalometric analysis.

Figure 12: Angular skeletal measurements used in lateral cephalometric analysis.

Figure 13: Linear skeletal measurements used in lateral cephalometric analysis.

Figure 14: Angular dental measurements used in lateral cephalometric analysis.

Figure 15: Linear dental measurements used in lateral cephalometric analysis.

Figure 16: Angular soft-tissue measurements used in lateral cephalometric analysis.

Figure 17: Linear soft-tissue measurements used in lateral cephalometric analysis.

Figure 18: Sagittal angular skeletal changes between T0 and T1.

Figure 19: Vertical angular skeletal changes between T0 and T1.

Figure 20: Sagittal linear skeletal changes between T0 and T1.

Figure 21: Vertical linear skeletal changes between T0 and T1.

Figure 22: Angular dental changes between T0 and T1.

Figure 23: Linear dental changes between T0 and T1.

Figure 24: Angular soft-tissue changes between T0 and T1.

Figure 25: Linear soft-tissue changes between T0 and T1.

Figure 26: Sagittal angular skeletal changes between T1 and T2.

Figure 27: Vertical angular skeletal changes between T1 and T2.

Figure 28: Sagittal linear skeletal changes between T1 and T2.

Figure 29: Vertical linear skeletal changes between T1 and T2.

Figure 30: Angular dental changes between T1 and T2.

Figure 31: Linear dental changes between T1 and T2.

Figure 32: Angular soft-tissue changes between T1 and T2.

Figure 33: Linear soft-tissue changes between T1 and T2.

Figure 34: Comparison of sagittal angular skeletal treatment changes between T0-T1 and T1-T2.

Figure 35: Comparison of vertical angular skeletal treatment changes between T0-T1 and T1-T2.

Figure 36: Comparison of sagittal linear skeletal treatment changes between T0-T1 and T1-T2.

Figure 37: Comparison of vertical linear skeletal treatment changes between T0-T1 and T1-T2.

Figure 38: Comparison of angular dental treatment changes between T0-T1 and T1-T2.

Figure 39: Comparison of linear dental treatment changes between T0-T1 and T1-T2.

Figure 40: Comparison of angular soft-tissue treatment changes between T0-T1 and T1-T2.

Figure 41: Comparison of linear soft-tissue treatment changes between T0-T1 and T1-T2.

1. SUMMARY

The aim of this study is to evaluate skeletal, dental and soft-tissue effects of *Forsus™ Fatigue Resistant Device* in growing Class II Division 1 individuals.

The sample consisted of 25 patients (16 males, 9 females), with mean age of 11 years 10 months ± 10 months. Skeletal and dental Class II Division 1 malocclusion, normal or mildly prognathic maxilla, retrognathic mandible, prepubertal growth period, normal or low angle growth pattern, permanent dentition, and minimum crowding were patient selection criteria.

Lateral cephalograms and hand-wrist radiographs were taken at the start of treatment (T0), before the application of the FRD (T1), and after the removal (T2).

We accepted the changes between T0-T1 as control values and compared with the changes between T1-T2.

Skeletally, the FRD restrained the maxilla. Condylar growth and total mandibular length were not affected. Lower anterior face height increased slightly.

Dentally, retraction and extrusion of the upper incisors, distalization of the upper molars, protrusion and intrusion of the lower incisors, mesialization of the lower molars, clockwise rotation of the occlusal plane and a reduction in overjet and overbite were observed.

Even though upper lip retraction was the only significant change, soft-tissue profiles favorably improved.

As a result, since the Cl II corrections were achieved mostly through dentoalveolar changes rather than skeletal, the FRD can also be used in nongrowing Class II patients taking low angle growth pattern and dentoalveolar retrusion as decisive criteria.

Key Words: Class II correction, Functional treatment, Forsus™ Fatigue Resistant Device.

2. ÖZET

FORSUS™ FATIGUE RESISTANT AYGITININ SINIF II BÖLÜM 1 OLGULAR ÜZERİNDEKİ İSKELETSEL VE DENTOALVEOLAR ETKİLERİ

Bu çalışmanın amacı *Forsus™ Fatigue Resistant Device* aygıtının büyümekte olan sınıf II bölüm 1 bireyler üzerindeki iskeletsel, dişsel ve yumuşak doku etkilerinin değerlendirilmesidir.

Çalışma grubunu ortalama yaşları 11 yaş 10 ay ± 10 ay olan 25 hasta (16 erkek, 9 kız) oluşturmuştur. Hasta seçim kriterleri iskeletsel ve dişsel Sınıf II bölüm 1 maloklüzyon, normal veya hafif prognatik maksilla, retrognatik mandibula, prepubertal büyüme periyodu, normal veya low angle büyüme modeli, daimi dentisyon ve minimum çapraşıklık olarak belirlenmiştir.

Lateral sefalogramlar ve el-bilek radyografları tedavinin başında (T0), FRD uygulanmadan hemen önce (T1), ve aygıt ağızdan çıkarıldıktan hemen sonra (T2) alınmıştır.

T0-T1 arasında meydana gelen değişiklikler kontrol değerleri olarak kabul edilmiş ve T1-T2 arasındaki değişikliklerle karşılaştırılmıştır.

İskeletsel olarak FRD, maksillayı baskılamıştır. Kondil büyümesi ve total mandibular uzunluk etkilenmemiştir. Alt yüz yüksekliği çok az artmıştır.

Dental olarak, üst keserler daha geride konumlanmış ve uzamışlar, üst molarlar distalize olmuşlar, alt keserler öne doğru devrilmiş ve gömülmüşler, alt molarlar mezyalize olmuşlar, okluzal düzlem saat yönünde rotasyon yapmış, overjet ve overbite azalmıştır.

Her ne kadar üst dudağın geride konumlanması tek anlamlı değişiklik olsa da yumuşak doku profili olumlu yönde gelişme göstermiştir.

Sonuç olarak, Sınıf II düzeltimi iskeletselden çok dentoalveolar değişikliklerle sağlandığından, low angle büyüme modeli ve dentoalveolar retrüzyonun karar verme kriterleri olarak kullanılmaları koşuluyla, FRD büyümesini tamamlamış Sınıf II hastalarda da kullanılabilir.

Anahtar Kelimeler: Sınıf II düzeltimi, Fonksiyonel tedavi, Forsus™ Fatigue Resistant Device.

3. INTRODUCTION and AIM

Cl II malocclusion with various combinations of skeletal and dental factors is a major and common problem in orthodontic practice. It constitutes about one-third of all orthodontic problems (293). The cause of skeletal Cl II malocclusion might be maxillary protrusion, mandibular retrusion, or both. McNamara reported mandibular retrusion as the most common characteristic of all Cl II malocclusions rather than maxillary prognathism (206). Consequently, advancement of mandible is the main goal in the treatment of the mandibular retrusion cases.

Repositioning of the mandible is called functional jaw orthopedics (206) and removable or fixed functional appliances are used to advance the mandible (40, 168, 244, 378).

Norman W. Kingsley first (1879) used forward positioning of the mandible in orthodontic treatment. His removable plate might be considered the prototype of functional appliances (179). Various types of functional appliance have been used to treat patients since then.

Although there is a wide variety of such appliances (e.g., activator, bionator, Herbst, Frankel, orthopedic corrector, Bimler), there are many similarities among them. In general, any functional appliance designed to correct a Class II malocclusion has some component that produces a change in the position of the mandible. This alteration in mandibular posture can be produced in a variety of ways, depending on whether or not the appliance is removable or fixed. An appliance that is fixed might be expected to have a greater dentoalveolar treatment effect than would an appliance that was removable, with only minimal contact of the teeth (212). On the other hand removable appliance requires perfect cooperation from the patient. Advantages and disadvantages of these appliances were reported in many investigations (84, 157, 247, 331).

Although they are commonly used during the pubertal growth period in children, the best timing for functional appliances has been controversial (178, 299). Some

investigators prefer to start treatment in prepubertal period (early treatment) (32), while another group prefers in postpubertal period (late treatment) (182).

Fixed functional appliances apply continuous light forces, thus eliminating patient cooperation and shortening treatment time. These devices can be categorized into two subgroups: semielastic (i.e., Eureka Spring, Twin Force Bite Corrector, Jasper Jumper, FRD) and rigid (i.e., Herbst, MARA) bite-jumping devices. Despite the increased patient acceptance and ease of application of the semielastic appliances, both groups demonstrate similar results regarding the dentoskeletal correction (187, 267, 350).

Forsus™ Fatigue Resistant Device (FRD) (90, http://solutions.3m.com/wps/portal/3M/en_US/orthodontics/Unitek/solutions/class-II/Forsus/) is a new fixed functional appliance. This device pushes the mandible forward and the maxilla backward applying continuous, light forces. However, in the literature, there are only a few original articles (98, 125, 173, 374) which clear out the skeletal and dental effects of this new fixed functional appliance.

The aim of this study is to evaluate skeletal, dental and soft-tissue effects of *Forsus™ Fatigue Resistant Device* in growing Class II Division 1 individuals.

4. LITERATURE REVIEW

4.1. Epidemiology

The prevalence of malocclusion varies in different parts of the world among various populations. Ethnic, genetic and environmental factors are the major contributors, with a role in the specific cause of malocclusion. Knowledge about the distribution of different malocclusions may help orthodontic practitioners better understand the existent problem in a geographic location and help them in the proper orientation and management of treatment possibilities.

Based on several thousand cases he examined, Angle suggested that an estimated 27% of malocclusion could be classified as Class II (5).

Numerous studies have been published regarding the prevalence of malocclusion in various populations. The results have shown wide variations. Differences in the age ranges of the populations studied, ethnicity, and the number of subjects examined could explain some of the variations. Moreover, differences in the registration methods are probably the most important factors explaining these variations.

Based on overjet greater than 4 mm, the National Health and Nutrition Examination Survey (NHANES III) data indicate an 11% prevalence of Class II malocclusion in the US population (298).

Considering the studies in The United States; Krogman (1951), in his study on children aged 6.5-12.5, found the prevalence of malocclusion as follows: normal occlusion 45.9%; Class I, 28%; Class II, 24.4% and Class III, 1.7%. Savara (1955), in his study on teenagers aged 14-17, reported the prevalence of malocclusion as follows: normal occlusion, 21.1%; Class I, 50.1%; Class II, 19.4% and Class III, 9.4%. Newman (1956), in his study on children and teenagers aged 6-14, reported the prevalence of malocclusion as follows: normal occlusion, 48.1%; Class I, 38.2%; Class II, 13.2% and Class III, 0.5%. Jackson and Brehm (1961), in their study on 6328 children and teenagers aged 6-18, reported the prevalence of malocclusion as

follows: normal occlusion, 16.6%; Class I, 60.1%; Class II, 22.8% and Class III, 0.5%. Emrich, Bordie and Blayney (1965), in their study on 13475 adolescents aged 12-14, reported the prevalence of malocclusion as follows: normal occlusion, 54%; Class I, 30%; Class II, 15% and Class III, 1%. Mills (1968), in his study on 1337 teenagers aged 13-14, and reported the prevalence of malocclusion as follows: normal occlusion, 17.5%; Class I, 72.2%; Class II, 6.6% and Class III, 3.7%. A study on 3289 black American adolescents aged 12-14, yielded the prevalence of malocclusion as follows: normal occlusion, 16.6%; Class I, 67.8%; Class II, 12.1% and Class III, 5%. A study on 651 Indian-American children and teenagers aged 6-18, revealed the prevalence of malocclusion as follows: normal occlusion, 34.6%; Class I, 53%; Class II, 9.5% and Class III, 2.9% (349).

Droschl found the frequency of Class II malocclusions to be 37% among the children between 6 and 15 years of age (96).

The epidemiological patterns of malocclusion in Scandinavian countries are well documented. Laine and Hausen recorded occlusal anomalies in 451 Finnish undergraduates and found distal molar occlusion (15%) the most common (188).

Helm (142) recorded occlusal anomalies of 1700 Danish children with permanent teeth and found the prevalence of Class II malocclusion 24%.

Thilander et al (362) recorded Class II malocclusion in 20.8% of 4724 children between 5-17 years of age.

Tausche et al (359) examined 1975 children aged between 6 and 8 years to estimate the prevalence of malocclusions using the Index of Orthodontic Treatment Need (IOTN) during the early mixed dentition period and found the prevalence of Class II 31.4%.

Gábris et al (116) examined a total of 483 Hungarian adolescents aged 16-18 years and 25.9% of subjects displayed a Class II Division 1 malocclusion.

Lux et al (200) orthodontically examined 494 nine-year-old German schoolchildren and found a Class II relationship of a three-quarter unit or more

affected more than every fifth child, which supports the significance of Class II malocclusions.

Borzabadi-Farahani et al (48) examined 502 urban Iranian school children. Cl II Division 1 malocclusion was present in 24.1% of the children in this cross-sectional study.

Perillo et al (283) performed a survey to determine orthodontic treatment need in a large sample (n = 703) of 12-year-old schoolchildren from the southern part of Italy. The prevalence rates for the Dental Health Component (DHC) of the Index of Orthodontic Treatment Need (IOTN) were calculated for the total sample. Cl II malocclusion prevalence rate was 36.3%.

Silva et al (341) examined a total of 507 twelve-eighteen years Latino adolescents between 1995 and 1999 in California. Class II malocclusion was diagnosed in 109 individuals (21.5%); 94.5% of those patients were Class II Division 1.

In 2005, Soh et al (347) determined the occlusal status in young Asian male adults (age 17-22 years) of three ethnic groups. The ethnic proportions of the sample were Chinese 76.1%, Malay 17.7%, and Indian 6.2%. British Standard Institute (BSI) and Angle's classification were used to determine incisor and molar relationship. The prevalence of Class II Division 1 malocclusion was 26.3%. Comparison between ethnic groups found that Indian subjects were more likely to have Class II/1 malocclusions.

In 1998, Ugur et al (367) collected data from 572 students ranging in age between 6 and 10 years of the Middle East Primary School with a high socioeconomic standard in Ankara. The findings were that 40.38% of the observed population showed normal occlusion and the rest showed minor or definite malocclusion.

In 2003, Arslan et al (11) examined 2297 individuals between 7-25 years in a retrospective study and they found the prevalence of Class II malocclusion 38,61%.

In 2004, Sayın et al (329) evaluated a total of 1356 patients (793 girls, 563 boys) from the southern regions of Turkey referred to the Department of Orthodontics, Suleyman Demirel University in their study. The mean age of the patients was 13.57 ± 3.16 years and none of the subjects had undergone previous orthodontic treatment. The prevalence of Class II Division 1 malocclusion was 19% and Class II Division malocclusion was 5%. The lowest mean age of a referred malocclusion was in the Class II Division 1 group. This finding may indicate that patients with Class II Division 1 were aware of their problems earlier than those in any other malocclusion group. According to results, the mean age of the referred population may indicate that motivation for and seeking of orthodontic treatment occurs during adolescence in a Turkish population sample.

In 2003, Sarı et al (324) examined 1602 patients referred to the Department of Orthodontics, Selçuk University and found the prevalence of Class II Division 1 malocclusion 25.1% and Class II Division 2 malocclusion 3%.

Although numerous studies have been published that describe the prevalence and types of malocclusion, it is difficult to compare and contrast these findings, in part because of the varying methods and indices used to assess and record occlusal relationships (21, 323, 358).

Other variables (including age differences of the study populations, examiner subjectivity, specific objectives, and differing sample sizes) further complicate efforts to understand and appreciate the differences recorded in patterns of malocclusion between ethnic groups (341).

4.2. ETIOLOGY

Etiology must be the first consideration in caring for any case of malocclusion; for unless the factors which have caused the deformity can be determined and removed, successful treatment is nor probable. Therefore, it is important to consider the etiology of Class II Division 1 malocclusion before going into the mechanics of its treatment.

Class II malocclusions have two basic causes (36, 37):

(1) Hereditary, or genetic factors

(2) Environmental factors

4.2.1. Hereditary, or Genetic Factors

Malocclusion could be produced by inherited characteristics. From an examination of longitudinal cephalometric radiographs and dental casts of siblings who participated in the Bolton-Brush growth study (carried out between the late 1930s and the early 1970s), Harris and Johnson (136) concluded that the heritability of craniofacial (skeletal) characteristics was relatively high, but that of dental (occlusal) characteristics was low. For skeletal characteristics, the heritability estimates increased with increasing age; for dental characteristics, the heritability estimates decreased, indicating an increasing environmental contribution to the dental variation. To the extent that the facial skeleton determines the characteristics of a malocclusion, therefore, a hereditary component is likely to be present, but purely dental variation seems to be much more environmentally determined.

Nakasima et al (227) assessed the role of heredity in the development of Angle's Class II malocclusion by comparing craniofacial morphologic differences between parents with Class II offspring and by analyzing the parent-offspring correlations. Lateral and frontal roentgenographic cephalograms were obtained for ninety-six patients with Class II malocclusion, and their respective parents. Mean cephalometric profile diagrams were superimposed between parents and their offspring. The parent-offspring correlation coefficients were computed for nineteen variables connecting

cephalometric landmarks. High correlation coefficient values were seen between parents and their offspring. Thus, there appears to be a strong familial tendency in the development of Class II malocclusions. They concluded that the hereditary pattern must be taken into consideration in the diagnosis and treatment of patients with this class of malocclusion.

Cassidy et al (68) studied the genetic influence on dental arch form in 320 adolescent orthodontic patients in 155 sibships. Forty-eight parameters grouped as tooth rotations, arch widths, arch depths, arch chords, and arch interrelationships were measured on plaster casts. Arch interrelationships were defined as (1) the distance along the occlusal plane between the mesiobuccal cusp tip of the maxillary permanent first molar and buccal groove of the mandibular permanent first molar basically, a quantitative measure of Angle's classification, and (2) incisor overjet. The heritability estimate for anteroposterior relationship of the first molars (Angle classification) was 56%, showing appreciable genetic influence. The heritability estimate for incisor overjet was 23%, indicating that overjet is primarily influenced by environmental factors.

Nakata et al (228) studied twins and their parents to estimate parent-offspring heritability. They used the mean value of a pair of parents and the mean value of a set of either monozygotic or same-sex dizygotic twins to obtain the regression coefficient of offspring and parent, as an estimation of the heritability. They also proposed a multiple regression equation as a method for predicting certain facial measurements in offspring, on the basis of parental data. The results showed high heritability for the 8 cephalometric variables studied, for both the parent-offspring data and the twin data. However, in most cases, the heritability estimates by offspring-parent regression were less than those obtained from the twin data, particularly for the 2 angular measurements used. They also reported that the father-offspring relationship was stronger than the mother-offspring relationship. The predictive value of each of the 8 cephalometric measurements in the offspring was increased when the values for these measurements and the stature of the parents were included in the calculation, together with the offspring's age and sex.

Saunders et al (328) studied the similarities in craniofacial dimensions on lateral cephalograms between family members. They calculated standard product-moment and intraclass correlation coefficients to compare parents with offspring and siblings with siblings. Their results showed a high level of significant correlations between first-degree relatives; these correlations are compatible with a polygenic theory of inheritance. The authors stated that the data did not give any evidence of added effects of autosomal dominance and sex linkage. Furthermore, in an attempt to predict a child's craniofacial dimensions, multiple regression analyses from both parents gave the best results.

Suzuki and Takahama (352) used posteroanterior and lateral cephalograms to estimate the morphologic similarities of craniofacial form between children and their parents. The findings showed that the craniofacial form of children was highly correlated with that of their parents. The genetic effects of determining the craniofacial form of offspring by the father were equivalent to those by the mother, but daughters were more affected by parents than were sons. The heritabilities of variables associated with craniofacial form ranged from 0.5 to 0.9. Variables representing the respiratory and masticatory systems were lower, ranging from 0.3 to 0.4. The investigators concluded that parental data were useful for predicting craniofacial growth in offspring.

In another study, Suzuki and Takahama (353) introduced a prediction model for the individual growth of children, based on parental data.

Johannsdottir et al (170) calculated the heritability of different cephalometric parameters, according to lateral cephalograms, between parents and their offspring in an Icelandic population. The subjects were 363 children (6 years of age) and their parents. Material was also collected from the same group of children at the age of 16 years. Heritability was calculated at ages 6 and 16. They found daughters having more variables that reached the level of significance than did sons. Daughters showed similar heritability to both parents at both age levels. Sons showed stronger heritability to their mothers at both ages. The variables showing the greatest heritability were those representing the position of the lower jaw, the anterior and

posterior face heights, and the cranial base dimensions. Heritability was notably low for the dental variables.

4.2.2. Environmental Factors

Environmental influences during the growth and development of the face, jaws, and teeth consist largely of pressures and forces related to physiologic activity. Function must adapt to the environment. For example, how you chew and swallow will be determined in part by what you have to eat; pressures against the jaws and teeth will occur during both activities and could affect how jaws grow and teeth erupt (293).

Nasopharyngeal disease and disturbed respiratory function which cause mouth breathing may alter craniofacial morphology. Disturbance of nasal respiratory function is etiologic to some skeletal Class II malocclusions. In mouth breathing, the muscles which depress the mandible to open the mouth exert a backward pressure upon it. This pressure not only tends to displace the mandible distally and retard its growth but also takes away the force of inclined plane relationship by holding the teeth apart. The combination of this distal force and loss of functional pressure results in a distal locking of inclined planes of the mandibular teeth with those of the maxillary. A continued backward pounding soon tips the lower molars mesially and retards normal growth in the mandible (33).

Other habits which are conducive to the development of this type of malocclusion are the various sucking habits, such as thumb or lip sucking. Abnormal swallowing habits are also factors. Thumb sucking habits will, if practiced over a period of time, cause a protrusion of the upper anterior teeth and a lack of development in the lower arch, which may develop into a typical Class II Division 1 malocclusion (344).

There are two swallowing habits in Class II Division 1 cases which tend to increase the malformation. One is the habit of forcing the lower lip under the

protruding upper anterior teeth when swallowing; the other is the habit of thrusting the tongue out between the anterior teeth (344).

Frankel (113) pointed out that a poor postural behavior of the musculature plays an important causative role in skeletal maldevelopment. Accordingly, he concluded that the main aim of a functional therapy is to trace a faulty postural performance of the orofacial musculature and to correct it by orthopedic exercises.

Woodside et al (388) selected a group of 38 (22 boys, 16 girls) children who had undergone adenoidectomy to relieve severe nasal obstruction and were available for study 5 years after the operation. None underwent orthodontic treatment before or during the experimental period. 37 (20 boys, 17 girls) children who had no history of nasal obstruction, nasorespiratory allergy, or recurrent otitis media and had never undergone adenoidectomy or orthodontic treatment were included as a control group. Records obtained for both groups before adenoidectomy consisted of study models, lateral and postero-anterior cephalograms, and airflow measurements. These records were repeated 1 year and 5 years later. They found that a change from mouth-open to mouth-closed breathing was associated with (1) Mandibular growth at the chin was significantly greater for both the boys and girls of the adenoidectomy group compared with their controls (2) greater facial growth expressed at the midface in males, and (3) no change in maxillary growth direction.

Craniofacial morphology follows the pattern of multifactorial inheritance, but the final product, the phenotype, must be the combination of genetic and environmental influences.

4.3. Dental and Skeletal Characteristics of Class II Malocclusion

It has been pointed out by many investigators (226, 325) that a Class II molar relationship occurs in a variety of skeletal and dental configurations.

4.3.1. Dental Characteristics of Class II Malocclusion

The publication of Angle's classification of malocclusion in the 1890s (4) was an important step in the development of orthodontics because it not only subdivided major types of malocclusion but also included the first clear and simple definition of normal occlusion in the natural dentition. Angle stated the following: In normal occlusion, the mesiobuccal cusp of the upper first molar is received in the sulcus between the mesial and distal buccal cusps of the lower [first molar]. The mesial and distal inclines of the mesiobuccal cusp of the upper first molar are received between the mesial and distal buccal cusps of the lower first molar. The inclines of the distobuccal cusp [of the upper first molar] are received between the distobuccal cusp of the first lower [molar] and the mesiobuccal cusp of the second lower [molar]. The mesial incline of the upper [canine] occludes with the distal incline of the lower [canine]; the distal incline of the upper [canine] occludes with the mesial incline of the buccal cusp of the lower first [premolar]. Each of the teeth in both jaws has two antagonists or supports in the opposite jaw, except the lower centrals and the upper third molars.

Angle stressed the importance of cuspal interdigitation to the establishment of normal occlusion during eruption of the teeth and to the maintenance of good occlusion. He stated that normal occlusion of the teeth is maintained first by the occlusal inclined planes of the cusps, second by the support given by the harmony in size of the upper and lower arches, and third by the influence of the muscles labially, buccally, and lingually. He concluded that these same three factors are also powerful in maintaining a malocclusion.

The Angle classification system for malocclusions proposed by Angle is widely used and serves as an excellent means of general description that has facilitated the communication about different malocclusions within the profession. The system basically describes anteroposterior relationships of the permanent first molars and canines.

According to Angle's classification system:

Class II: The relative mesiodistal relations of the dental arches are abnormal with all the lower teeth occluding distal to normal, producing a marked disharmony in the incisor region and in the facial lines. In full Class II, the distobuccal cusp of the permanent upper first molar fits into the sulcus between the mesial and middle buccal cusps of the lower first molar. The mandible is retrusive (in a more posterior or dorsal position than normal).

Division 1: A Class II Division 1 malocclusion is characterized by a narrowing of the upper arch, lengthened and protruding upper incisors, abnormal function of the lips, and some form of nasal obstruction and mouth breathing.

Division 2: A Class II Division 2 malocclusion is characterized by a slight narrowing of the upper arch, bunching (crowding) of the upper incisors with overlapping and lingual inclination, and normal nasal and lip function.

Subdivision: A Class II subdivision malocclusion has a normal occlusal relation on one side of the arches and a Class II occlusion on the other side.

Angle included in his description of malocclusions not only the positions and relations of the teeth, but also information about arch width, the retrusion or protrusion of the mandible, the effects of the malocclusion on the face, abnormal lip function, and the association of nasal obstruction and mouth breathing with malocclusion. Angle wrote his descriptions of malocclusions more than 30 years before the advent of cephalometric radiographs. Cephalometric measurements help clinicians differentiate malocclusions more accurately in patients who have normal skeletal relations between the maxilla and mandible from those who have abnormal relations between the maxilla and mandible. Furthermore, the determination of whether the discrepancy is in one or both jaws is made easier with cephalometric radiographs (34).

Cephalometric radiography came into widespread use after World War II. These radiographs made it clear that many Class II and Class III malocclusions resulted

from faulty jaw relationships, not just malposed teeth. By use of cephalometrics, it also was possible to see that jaw growth could be altered by orthodontic treatment. In Europe, the method of "functional jaw orthopedics" was developed to enhance growth changes, while in the United States, extraoral force came to be used for this purpose. At present, both functional and extraoral appliances are used internationally to control and modify growth and form problems (294).

According to Bishara (35) the causes of dental Class II malocclusions can be subdivided into two groups: (1) maxillary dental protrusion and (2) mesial drift of the maxillary first permanent molars.

Maxillary Dental Protrusion Maxillary dental protrusion is not a skeletal problem but a dentoalveolar one that is limited to the maxillary dental arch. It only affects the lips. Excessive overjet is a reliable feature of this dental malocclusion, and there may be generalized maxillary spacing associated with the protruded maxillary incisors. The mandible and mandibular dentition are in a normal anteroposterior position. The cephalometric presentation of maxillary dental protrusion shows a normal anteroposterior and vertical skeletal relationship. The mandibular incisors also will be in a normal anteroposterior position. The departure from normal values will be the maxillary incisors, which will be in a protrusive position.

Mesial Drift of the Maxillary First Permanent Molars Normal eruption of permanent teeth is dependent on the normal position and integrity of the primary teeth. Congenital absence or loss of the primary teeth before normal exfoliation may disturb the normal eruption of permanent teeth. This is particularly the case with the premature loss of posterior primary teeth. Mesial and occlusal drift of the permanent first molars occurs if there is loss of mesial proximal contact with the second primary molars from congenital absence, extraction, dental caries or ankylosis. The mesial drift is more pronounced if the lack of proximal contact occurs in the maxilla or if the loss occurs before clinical emergence of the first permanent molar. Ectopic molar eruption, in which the eruption of the first permanent molar causes premature root resorption of the adjacent primary second molar, also occurs more frequently in the maxillary arch.

In both of these situations, if left untreated, the maxillary first permanent molar assumes a more mesial position, resulting in a Class II permanent molar relationship if the mandibular arch is unaffected.

4.3.1.1. Dental Arch Shape and Characteristics

Fröhlich (115) compared the dental development in children with Class II type malocclusions who did not undergo orthodontic treatment. Serial dental casts of 51 children were selected from a total of 405 children studied in a longitudinal survey. In general, the period of observation included the transition from the deciduous to the permanent dentition. He divided the sample into four subgroups. The subgroups are described as follows:

Class II Division 2: Characterized by the typical lingual inclination of the permanent maxillary central incisors and flaring of the lateral incisors, broad maxillary dental arch and deep overbite.

Class II, borderline between Division 2 and Division 1: Characterized by an upright position and good alignment of the maxillary dental arch.

Class II Division 1 V- shaped: Characterized by an overjet and severe crowding of the permanent maxillary incisors as well as V- shaped maxillary dental arch.

Class II Division 1 flaring and spacing: Characterized by flaring and spacing of the permanent maxillary incisors, marked overjet and parabolic maxillary arch shape.

He concluded: 1. The absolute dental arch length and arch breadth do not differ appreciably from the normative data. 2. Differences between the maxillary arch dimensions of the four subgroups are revealed. 3. No specific trends characterize the dimensions of the mandibular dental arch. 4. The increments in the maxillary and mandibular arch lengths in these children between six and twelve years tend to be greater than those of children with normal dentition. 5. The increments in the maxillary and mandibular arch breadths between six and twelve years conform to the normative pattern. 6. The four subgroups are difficult to distinguish at an early age. They seem to have a similar morphologic pattern in the deciduous dentition

(semicircular arch shape, retrusive positions of the maxillary incisor, and spacing of the anterior segment). 7. The four subgroups can be differentiated only after the eruption of the permanent maxillary incisors. 8. In the maxilla, the canines separate the more variable anterior segment from the more stable posterior segment. 9. Both overbite and especially overjet increase in untreated Class II malocclusions. 10. Generally, the sagittal relation of the dental arches does not improve with age and either remains the same or the distocclusion is intensified. 11. Since the malrelation of the dental arches increases, it is of no advantage to postpone therapeutic measures once the distoclusion is observed. 12. A wide range of individual variations exists (115).

Bishara implies that in a Class II malocclusion case maxillary dental arch is more narrow or constricted than normal because it is in occlusion with a narrower part of the mandibular dental arch. This transverse dental compensation is characterized further by mesiolingual rotation of the maxillary first molars (35).

Bishara et al (38) aimed to determine on a longitudinal basis whether the growth trends in maxillary and mandibular dental arch widths and lengths in persons with Class II, Division 1 malocclusions were different from those of normal subjects. Dental casts were available on a total of 37 subjects with Class II, Division 1 malocclusions (15 males and 22 females) and 55 normal subjects (28 males and 27 females). For each subject, three sets of casts were evaluated at the following developmental stages: (1) deciduous dentition; (2) mixed dentition; and (3) permanent dentition. The results of the study indicates that the growth trends in the various dental arch parameters evaluated were similar in the normal and Class II, Division 1 malocclusion groups. In addition, the differences between the measurements of maxillary and mandibular intermolar arch widths were greater in the normal subjects than in the subjects with Class II, Division 1 malocclusions. They concluded that the clinician should assume that the changes in arch lengths and widths in both the subjects with Class II, Division 1 malocclusions and the normal subjects follow the same general patterns. On the other hand, the relative constriction of the maxillary arch as related to the mandibular arch, in Class II malocclusions is expressed from the earlier stages of dental arch development. These trends continue

in the mixed and early permanent dentitions and do not self correct without treatment. Therefore when such trends are diagnosed, early correction of the transverse discrepancy should be attempted together with that of the anteroposterior discrepancy.

Buschang et al (58) evaluated differences in dental arch morphology among an orthodontic sample of 386 untreated adult females between 17 and 68 years of age, categorized by age group (17–25 years, 26–35 years, or 35+ years) and malocclusion (Class I, Class II Division 1, or Class II Division 2). The results show that subjects with Class II malocclusion had significantly smaller arches, greater maxillary incisor irregularity, and less mandibular incisor irregularity than patients with Class I malocclusion. Subjects with Class II Division 1 malocclusion had greater palatal heights and relatively longer/narrower maxillary dental arches than subjects with Class II Division 2 malocclusion.

Nie et al (239) compared dental arch forms between 60 subjects with Class II Division 1 malocclusions and 60 subjects with normal occlusions, all between 13 and 17 years of age. The results showed that in both sexes, the maxillary arches of the Class II Division 1 subjects were larger than the arches of the normal-occlusion subjects and arch shape was also different. The posterior teeth contributed to the shape difference between 2 groups more than the anterior teeth, moreover the main factor was narrow maxillary posterior arch width in the Class II Division 1 subjects. The mandibular arches of the Class II Division 1 subjects were also slightly larger, and arch shape was not significantly different regardless of sex.

Baccetti et al (13) compared a group of 25 untreated subjects with Class II malocclusion in the deciduous dentition with a control group of 22 untreated subjects with ideal occlusion at the same dentitional stage. The subjects were monitored during a 2-year period in the transition from the deciduous to the mixed dentition, during which time no orthodontic treatment was provided. Occlusal analysis of the Class II group in the deciduous dentition revealed an average interarch transverse discrepancy due to a narrow maxillary arch relative to the mandible. All occlusal Class II features were maintained or became exaggerated during the transition to the mixed dentition.

4.3.2. Skeletal Characteristics of Class II Malocclusion

Angle's original simplified approach was inadequate to describe the diversity of Class II malocclusion arising from both dental and skeletal origin.

Despite in 1928 Oppenheim compared anthropometric measurements from a series of skulls having normal occlusion with those exhibiting Class II malocclusions and concluded 'the fact that prosthion and subspinale in the overwhelming majority of Class II cases are situated even further back than in normal cases, precludes the assumption that the anomaly in Class II cases is located in the upper jaw,' and 'the Class II anomaly consists (with few exceptions) in underdevelopment of the mandible.'

In 1931 Broadbent devised a method of standardizing orthodiagraphic roentgenograms, using a head-positioning device similar to the Todd craniostat, which had been designed for use on dried skulls. This method greatly facilitated the study of head morphology, and made possible the use of relatively stable landmarks within the skull. Measurements of comparatively high precision are made possible by graded scales incorporated in the roentgenogram. Serial studies of facial growth were possible (95).

Bishara (35) illustrated that the introduction of standardized cephalometric radiographs and their widespread use in clinical orthodontics in the second half of the twentieth century permitted further appreciation of the dental and skeletal features that may be associated with individuals who have Class II malocclusions. Angle's classification was extended by the next generation of orthodontists to describe anteroposterior skeletal discrepancies or disproportions of the maxilla and the mandible. Skeletal discrepancies associated with Class II malocclusions have been termed as 'skeletal Class II relationships'. This term indicates that the Class II malocclusion is one resulting from an anteroposterior disproportion in size or discrepancy in position of the jaws rather than malposition of the teeth relative to the jaws (retrusion of mandibular teeth or protrusion of maxillary teeth or both).

These skeletal Class II relationships often are associated with Class II dental malocclusions. Typically, some natural dental compensation is observed in the

presence of the skeletal discrepancy. This compensation tends to make the dental discrepancy less severe than the skeletal discrepancy and is exhibited most often as protrusive mandibular incisors and less frequently as retrusive maxillary incisors. Skeletal Class II malocclusions can be subdivided conveniently into those comprised of either;

1. Mandibular deficiency,
2. Maxillary excess,
3. Combination of mandibular deficiency and maxillary excess.

Mandibular Deficiency Caused by Size or Position A skeletal Class II relationship resulting from a mandible that is small or retruded relative to the maxilla is termed as *mandibular deficiency.* Regardless of whether the mandibular deficiency is an absolute deficiency (because of size) or a relative deficiency (because of position), the resulting anteroposterior dental relationship is usually Class II. The patient with this condition typically presents with a facial appearance characterized by a normal nasolabial angle, relative protrusion of the maxillary anterior teeth and a relative deficiency of the chin caused by the small size or retruded position of the mandible.

One manifestation of mandibular deficiency in cephalometric analysis is exhibited as a downward and backward rotation of the mandible caused by the small size of the ramus and body of the mandible. This relationship often results in a decreased posterior facial height, a steeper mandibular plane angle, an increased ANB angle, a normal SNA angle with a decreased SNB angle, an increased angle of convexity, and an increased overjet. There is an increased A-B difference depicted as a greater positive value by the WITS analysis. Another distinguishing cephalometric measurement is a normal position of point A but a posterior position of point B relative to Nasion perpendicular. Excessive overjet is the feature that was used by Angle to distinguish his classification of Class II Division 1. The overjet may become more severe if the anteroposterior discrepancy between the maxillary and mandibular teeth is great enough to cause the lower lip to be positioned lingual to the maxillary incisors, further protruding them. Excessive overjet prevents occlusion between the maxillary and mandibular incisors which may result in overeruption,

causing an excessive anterior overbite. It is common in a severe mandibular deficiency to have dental compensation for the skeletal disproportion displayed cephalometrically as protruded mandibular incisors (increased angulation of mandibular incisors relative to mandibular plane or N-B line and a decreased angulation relative to the occlusal plane or Frankfort horizontal).

Another variation of mandibular deficiency is one in which the decreased size is localized more to the mandibular body with mandibular rami of normal or increased length. This usually appears cephalometrically as normal or increased posterior face height and a flatter mandibular plane. Linear assessment of mandibular length as measured from Ar to Gn or Pog may appear normal because of an excessive bony chin projection. This type of mandibular deficiency is often associated with a deep anterior overbite with the maxillary incisors lingually inclined, decreasing overjet and further masking the anteroposterior dental discrepancy. The lingual inclination of the maxillary incisors and reduced overjet are the features that distinguish Angle's Class II Division *2* classification. Although there is a prevailing empirical belief that there is distinguishing skeletal and facial differences between individuals with Division 1 and Division 2 Class II malocclusions, there is support that no such distinction exists.

Individuals with mandibular deficiency resulting from retrusion of a normal-sized mandible share cephalometric features of other types of mandibular deficiency with respect to points A and B relative to Sella and the occlusal plane. The cranial base angle, defined by points Nasion, Sella, and Basion, often is more obtuse with the glenoid fossa in a relatively posterior position. The distinguishing characteristics will be the normal size of the mandibular ramus and body, usually resulting in normal mandibular linear anteroposterior length and a normal lower face height in spite of the anteroposterior discrepancy between the maxilla and mandible (35).

Maxillary Excess Maxillary excess frequently may be the underlying skeletal cause of a Class II malocclusion. Maxillary excess may present as overdevelopment in the vertical or anteroposterior dimension or both. In the case of vertical maxillary excess, the excess may be more localized to the posterior area, associated with the maxillary posterior teeth being in an inferior position with a normal vertical position

of the incisors. This condition is usually associated with an anterior open bite but with a normal vertical display of the maxillary incisors relative to the upper lip both in repose and upon smiling. Vertical maxillary excess also may present as overall excess with the anterior as well as the posterior maxillary teeth located inferiorly. In this condition there will be no anterior open bite, but there will be an excessive vertical display of the maxillary incisors relative to the upper lip in repose as well as a gummy smile (excessive exposure of the gingiva upon smiling). In either of these two presentations of vertical maxillary excess, the mandible is rotated downward and posteriorly (the term clockwise rotation often is used), resulting in the Class II skeletal relationship.

With vertical maxillary excess the mandible may be of normal size but in a retrusive position because of the inferior position of the maxilla. The facial presentation of an individual with this skeletal deformity may not appear different from the mandibular deficiency when viewed by the untrained eye. However, the facial appearance often includes a narrow nose with a prominent dorsum and narrow alar bases. There is usually an increased lower anterior face height with a normal or obtuse nasolabial angle. As with the mandibular deficiency, there will be a relative chin retrusion and relative maxillary incisor protrusion because of the anteroposterior jaw discrepancy. Cephalometrically, the vertical maxillary excess is typified by an increased anterior face height and steeper mandibular plane angle. Just as with mandibular deficiency, vertical maxillary excess is usually characterized by an increased ANB angle, a normal SNA angle with a decreased SNB angle, an increased angle of convexity, and an increased overjet. Although there is usually an increased distance between points A and B as projected on the occlusal plane (WITS), this difference may be minimized by the steepness of the occlusal plane. When projected on a true horizontal line, the anteroposterior skeletal discrepancy becomes more readily apparent. Just as with the mandibular deficiency, A point appears in a normal anteroposterior position and B point appears in a posterior position relative to Nasion perpendicular. The anteroposterior discrepancy usually results in dental compensation with mandibular incisor protrusion similar to the mandibular deficient condition. However, anteroposterior mandibular length may appear normal relative to anteroposterior maxillary length. The most distinguishing cephalometric features

of the vertical maxillary excess are in the vertical plane and include an increased lower anterior face height, steeper mandibular plane angle, and more inferior position of maxillary molars relative to the palatal plane. If the vertical excess includes the anterior part of the maxilla, the maxillary incisors will also be in a more inferior position relative to the palatal plane.

It is possible, although less common, to have maxillary excess in the anteroposterior dimension or midface protrusion. The facial appearance of this deformity can be easily confused with maxillary dental protrusion. Although both conditions exhibit facial skeletal convexity with a normal anteroposterior position of the mandible, maxillary anteroposterior excess is characterized by a protrusion of the entire midface, including the nose and infraorbital area as well as the upper lip. Cephalometric features of anteroposterior maxillary excess, as with all skeletal Class II relationships, typically include an increased ANB angle and A-B difference projected on occlusal plane (WITS analysis) and true horizontal line, as well as increased facial convexity. In addition, however, SNA angle usually is increased. In contrast to mandibular deficiency, SNB angle is normal, A point is anterior, and B point is normal relative to Nasion perpendicular. Anteroposterior maxillary length is increased and anteroposterior mandibular length usually is normal. As with the other types of skeletal Class II relationships, there usually is anteroposterior dental compensation in the form of mandibular incisor protrusion and transverse dental compensation in the form of maxillary constriction. The excessive overjet usually is associated with overeruption of the mandibular incisors and excessive overbite. If the midface protrusion is severe, the lower lip may play a similar role as with the severe mandibular deficiency with its position lingual to the maxillary incisors encouraging their protrusion and overeruption. It is important for the clinician to remember that in the numeric interpretation of the cephalometric measurements, a steep cant of the anterior cranial base or an anterior displacement of Nasion can influence the magnitude of these angles. Therefore such anatomic variations should be taken into consideration during cephalometric interpretations (35).

Combination of Mandibular Deficiency and Maxillary Excess It is common to have a combination of mandibular deficiency and maxillary excess, each of which

would add to the severity of the anteroposterior skeletal problem. It is likely that most patients with skeletal Class II problems have a combination of mandibular deficiency and maxillary excess (35).

In the literature there is such a variety of opinions among researchers about the skeletal positions of Class II patients. No common results have been found regarding cranial base configurations.

In 1948 Drelich (95) certain characteristics of the facial patterns of two randomly selected groups, namely, an untreated group of patients having excellent occlusion and a comparable group of patients exhibiting Class II Division 1 malocclusion. He concluded that the chin in Class II Division 1 is located more posteriorly and the length of the madible in Class II Division 1 is shorter. The lower posterior face height was less in Class II group than in the normal group indicating a relatively steeper mandibular plane angle in the malocclusion group.

In 1951 Craig (85) evaluated 34 Class I cases and 36 Class II Division 1 cases all of which are 12 years of age. The investigation indicated that the basic reason for the molar relationship in the Class II Division 1 malocclusion lies in the fact that the mandibular body is shorter than in Class I.

McNamara (206) evaluated lateral cephalometric radiographs of 277 children with Class II malocclusion between the ages of 8 and 10 years. The following conclusions were drawn: (1) Class II malocclusion is not a single clinical entity. It can result from numerous combinations of skeletal and dental components. (2) Only a small percentage of the cases in the study exhibited maxillary skeletal protrusion relative to cranial and cranial base structures. On the average, the maxilla was in a neutral position, and when not in a neutral position, it was more often in a retruded than protruded position. (3) The degree of maxillary dental protrusion observed in the study was less than that reported by most previous investigators. (4) The lower incisors were usually well-positioned but cases of mandibular dental retrusion and protrusion were also noted. (5) Mandibular skeletal retrusion was the most common single characteristic of the Class II sample. (6) Almost half of the sample exhibited excessive vertical development.

Sayın et al (330) evaluated 40 nongrowing females having a skeletal and dental Class II Division 1 malocclusion and compared with 20 nongrowing females having skeletal Class I pattern and ideal occlusion. They observed wide variations for almost all measurements of Class II Division 1 patients, but on average, the maxilla of Class II Division 1 patients was normally positioned. However, their mandibles were smaller in size, posteriorly positioned, and rotated open when compared with Class I subjects. The cranial base angle was larger in Class II Division 1 patients. Also, the anterior and posterior cranial lengths were shorter in the Class II group.

Bacon et al (16) compared cranial base size and shape, and facial divergence in two groups between 10 and 12 years old: an experimental group of 45 subjects with dental and skeletal Class II and a homologous control group of 41 subjects with a natural Class I ideal occlusion. The anterior part of the cranial base (SN length and SNBa angle) was identical in the two groups, but in Class II, cranial base flexure (BaSN angle) was more obtuse and posterior cranial base angle (SBaN) was more acute. These variations co-existed in the same group with a more retruded position of the condylar neck in the face favoring *per se* a post-normal relationship of the mandible to the maxilla. The increased extension of the saddle angle in Class II could not be considered here as related to a hyperdivergent facial pattern since facial divergence was unchanged in Class II. Saddle angle and divergence correlated in Class I, but not in Class II. A multivariate discriminant analysis would reclassify 62 per cent of the Class II and 66 per cent of the control group. This result indicates that a relation may exist between cranial base configuration and post-normal occlusion, even if cranial base contribution is far from being decisive in most of the Class II.

Rothstein et al (311) examined material included 613 lateral head radiographs comprising 2 series: (1) 278 films of children with "normal" occlusion and (2) 335 films of children with Class II, Division 1 malocclusion ranging from 8.5 to 15.5 years. It was found that: (1) the mandible and its dentition is similar to the controls in size, form, and position except for the position of the lower incisors in males; (2) the forehead (Gl), anterior cranial base (Nas), maxilla (A) and dentition (molars and incisors) are protrusive (mesial positioned), with an increased frontal bone thickness at the level of the sinus, and a larger A-P maxilla, the palate of which is inclined

superiorly at its anterior half; (3) no vertical dysplasia was evident; (4) the cranial base angle is larger, as are the anterior and posterior sections that compose it, but it is not related to mandibular position; (5) angular indexes of maxillary and mandibular position that included point Nasion are highly misleading indicators of maxillary and mandibular size and position. They pointed out that enlarged sinuses may contribute to the cause of Class II, Division 1 malocclusion.

Rosenblum (307) evaluated 103 Class II subjects between the ages of 11-16. He reported that 27 % of the sample had mandibular retrusion, while 56,3% of the sample having maxillary protrusion.

Brezniak et al (51) described the skeletal and dentoalveolar cephalometric characteristics of 50 patients clinically diagnosed as having Class II Division 2 malocclusion according to Angle's original criteria. They compared the findings with those of both a control group of 54 subjects with Class II Division 1 malocclusion and a second control group of 34 subjects with Class I malocclusion. The findings demonstrated definite skeletal and dentoalveolar patterns with the following characteristics: (1) the maxilla is orthognathic, (2) the mandible has relatively short and retrognathic parameters, (3) the chin is relatively prominent, (4) the facial pattern is hypodivergent, (5) the upper central incisors are retroclined, and (6) the overbite is deep.

Pancherz et al (266) compared the dentoskeletal morphology in 347 Class II Division 1 and 156 Class II Division 2 malocclusions using lateral cephalometric radiographs. Children at the ages of 8-10 years and 11-13 years were evaluated. In conclusion they found that, except for the position of the maxillary incisors, no basic difference in dentoskeletal morphology exists between Class II Division 1 and Class II Division 2 malocclusions.

4.3.3. Soft-tissue Characteristics of Class II Division 1 Malocclusion

Soft-tissue characteristics differ according to the affected jaw in Class II Division 1 malocclusion:

Mandibular Deficiency The lower lip tends to be more everted or redundant, resulting in a pronounced labiomental fold. This is the result of the lingual contact of the maxillary incisors with the lower lip, which prevents it from being supported by the mandibular incisors. If the deficiency is great enough, the lower lip will be positioned lingually to the maxillary incisors at rest (everted lower lip), resulting in lip incompetence (i.e., an absence of upper and lower lip apposition). The consequence of this resting lip position is further protrusion of the maxillary incisors. This lip posture also prevents the lower lip from providing adequate vertical support for the maxillary incisors, promoting overeruption of these incisors (35).

If there is a decreased size mandibular body with mandibular rami of normal or increased length, mandibular length may appear normal as measured from Ar to Gn or Pog because of an excessive bony chin projection. This chin projection may be great enough to mask the facial appearance of the mandibular deficiency, but it may still leave a lack of support for the lower lip. These individuals typically have a short lower anterior face height, often resulting in both the upper and lower lips having a more everted position at rest (35).

Maxillary excess If the excess is localized to the posterior area, associated with the maxillary posterior teeth being in an inferior position with a normal vertical position of the incisors, there will be an anterior openbite and the lips incompetent.

With vertical maxillary excess and the mandible of normal size but in a retrusive position because of the inferior position of the maxilla, the facial presentation of an individual may not appear different from the mandibular. The facial appearance often includes a narrow nose with a prominent dorsum and narrow alar bases. There is usually an increased lower anterior face height with a normal or obtuse nasolabial angle. Lip incompetence, or lack of lip apposition at rest, is even more common with maxillary vertical excess than with mandibular deficiency because the increased vertical height of the lower face causes the lips to be apart vertically, adding to the anteroposterior lip separation caused by the mandibular retrusion.

Brodie (55) implies that in Class II Division 1 cases the mandible, being retruded in relation to the maxilla, breaks the union of the lips, the upper of which

curls up over the roots of the maxillary teeth. Increased strain from the external oblique line through the triangularis muscle to the upper lip crushes the canines lingually, and the muscle balance is completely altered, although the muscles themselves may be perfectly normal.

Hoffelder et al (149) investigated changes in the thickness and the length of the soft-tissues of the nose, upper and lower lips, and chin due to growth from 6 to 16 years of age. Cephalograms of 36 subjects (22 boys, 15 girls) with skeletal Class II malocclusions were analyzed. Longitudinal records had been collected at ages 6, 9, 12, 14, and 16 years. Results showed that all structures showed some growth at all stages. The nose showed the greatest increases in thickness and length in both sexes. There was sexual dimorphism at 16 years, with higher values for boys. Upper lips tended to reduce in the girls. Upper lip length showed slight increases, and base of the upper lip showed small increases for both sexes. The lower lip had moderate increases in all measurements, and its thickness showed sexual dimorphism at almost all ages. The soft-tissues of the chin increased in both thickness and length, with no sexual dimorphism.

4.3.4. Perioral Functional Characteristics of Class II Division 1 Malocclusion

It has been recognized for many years that muscle function influences bone formation and morphology. Woodside et al (387) hypothesized that the movement of bone into new positions within a muscle system results in rearrangement of the stress distribution and reorganization of shape and internal structure. To test the above hypothesis, clinical and animal experiments involving the use of posterior occlusal bite blocks, Herbst appliances, and temporal and masseter muscle stimulation were undertaken. Chronic or continuous alteration in mandibular position with neuromuscular environment with the posterior occlusal bite block and Herbst appliance in a sample of monkeys produced extensive condylar remodeling and change in mandibular size. Short periods of induced hyperactivity in the masseter and temporal muscles were associated with the production of malocclusion symptoms. Excess induced temporal muscle activity or specific frequency and

intensity may interfere with the remodeling of bone grafts placed under the temporal muscle, while a lesser level of activity was associated with bone remodeling.

Jacobs and Brodie (160) showed that the ratio of maxillary tonus to mandibular tonus rises to its highest value in Class II Division 1 malocclusion. As a result of anteroposterior disharmony of mandibulomaxillary skeletal base relation the mandibular attachments of the modiolar muscles are displaced posteriorly. This does not alter significantly the length of the triangularis muscle because of its vertical and slightly oblique course. The buccinator muscle, however, runs anteroposteriorly and therefore a retrognathic position of the mandible represents a most effective line for elongation and stretch of its inferior peripheral filaments. Under normal conditions these fibers, when at rest, are longer than the distance between their fixed points, *i.e.*, origin from external oblique line and modiolar insertion and, therefore, they control the modiolar fixation to a minor extent only. The increased static tension of these filaments produces a disturbance of muscular equilibrium and brings about a posteroinferior shift of the modiolar pivot which may have the following effects: (1) stretch and increased tension of the caninus muscle and maxillary portion of the orbicularis oris with the resulting increase of the maxillary vestibular tonus; (2) shortening of the triangularis and platysma muscles and consequent decrease of the tonus of these muscles with a resulting decline of mandibular static tensions; (3) possible eversion of lower lip.

They added that this syndrome usually involves perversion of tongue movements and hyperactivity of the mentalis muscle which represent expersion of an adaptive effort to sustain oral seal during deglutition.

The posteroinferior displacement of the modiolus with the resulting increase of static tensions in the maxillary vestibule is probably responsible for the narrowing of the maxillary arch and may possibly explain the change of arch shape from triangular to semicircular (56).

The distribution of tonic forces is altered in cases with Class II malocclusion. The differential factor is provided by the absence of protrusion of the maxillary denture which may have the following effects: (1) Lowering of the tonus in the

maxillary portion of orbicularis oris muscle and decrease of maxillary vestibular forces. (2) Intensified tonic forces exerted by the posteriorly displaced, inferior fibers of the buccinator are not offset by a stressed orbicularis oris muscle, as in Class II Division 1, Consequently, posteroinferior shift of the modiolar pivot is more severe in Class II Division 2 than in Class II Division 1. This may only be a factor which augments the inferior vector of force exerted upon the anterior segment of the maxillary denture, producing a deep overbite and inverse curve of spee (54).

Pancherz (245) performed a quantitative analysis of EMG activity in the masticatory muscles in homogeneous groups of boys with Class II, Division I malocclusion and normal occlusion. Integrated EMG recordings from the temporal and masseter muscles were analyzed during maximal biting in the intercuspal position (centric occlusion) and during the chewing of peanuts. The results of the investigation revealed the following: (1) During maximal biting in intercuspal position the boys with Class II malocclusion exhibited less EMG activity in the masseter and temporal muscles than the boys with normal occlusion. In the Class II boys the reduction in EMG activity was most apparent for the masseter muscle. (2) During chewing the Class II subjects showed less EMG activity in the masseter muscle than the normal occlusion subjects. For the temporal muscle, no differences were found between the two occlusion groups. (3) High positive correlations were found between the EMG activity during maximal biting and chewing for both muscles in the two occlusion groups.

4.3.5. Condyle Position in Class II Division 1 Malocclusion

Ricketts (303) compared 100 joints of 50 individuals who have Class II malocclusion with the same number of ones none of whom had any clinical manifestation of joint disturbance. The study revealed that the position of the condyle in the fossa had been found to be essentially the same in the control and Class II samples when the teeth were in full occlusion. The most startling difference between the two groups was the position of the mandible at rest. The control group exhibited

the accepted condyle-fossa relation whereas the Class II sample revealed the condyle downward and forward in the fossa.

Pullinger et al (300) investigated the influence of occlusion on condylar position as seen on TMJ nomograms in a group of 44 young adults with no histories of orthodontic or occlusal therapy and no objective signs of masticatory dysfunction. They concluded that Class II malocclusion was associated with more nonconcentric condylar positions than Class I, with the position in Class II, Division 1 being more frequently anterior. Condylar position was not related to the direction of dental midline discrepancy or the overbite or overjet relationships occurring in the sample.

Komposch (181) observed a posterior rotation of the condyles, an increased cartilage layer in the posterior and resorption in the anterior zone of the condyle, and anterior lengthening of the glenoid fossa with morphological posterior translation of the mandibular ramus.

Vitral et al (373) evaluated thirty persons with Class II Division 1 subdivision malocclusions, ranging in age from 12 years 8 months to 42 years. Patients underwent computed tomography of the temporomandibular joints in order to assess the depth of the mandibular fossa, the angulation of the posterior wall of the articular tubercle, the condyle-fossa relationship, and the concentric position of the condyles associated with this malocclusion. Measurements on both Class I and Class II sides were obtained. They found that there were no differences between sides I (Class I) and II (Class II) in the condyle-fossa relationship, the depth of the mandibular fossa, and the angulation of the posterior wall of the articular tubercle in the sample of Class II Division 1 subdivision patients. Evaluation of the concentric position of the condyles in their respective mandibular fossa showed a nonconcentric positioning for side I and side II; this demonstrates a statistically significant anteriorly positioned condyle.

Cohlmia et al (80) evaluated the morphologic relationship of the condyle and fossa in 232 patients with different malocclusions and skeletal relationships. Findings showed that skeletal and dental Class III patients demonstrated more anteriorly

positioned condyles. There were no significant differences in condylar position between Class I and Class II groups.

Peltola et al (281) evaluated pretreatment panoramic radiographs of 625 orthodontic patients (269 males and 356 females), aged 4-15.9 years with special emphasis on the mandibular condyles and malocclusions. Seven different types of radiological characteristics in the condyles were recorded (flattening of the articular surface; subcortical sclerosis (eburnation); osteophyte; microcyst; marginal erosion; periarticular ossicle; other changes, including deformities). Angle Class II molar relationship was the only type of morphological malocclusion associated with condylar characteristics.

Tadej et al (355) examined a study consisting 104 orthodontic patients prior to treatment. The size and location of the condyle was determined on submento-vertex and tomographic films which was related to clinical findings including age, sex, malocclusion type, facial type, TMJ symptoms, tooth eruption sequence, crossbites and midline discrepancies. He revealed that transversal anomalies had a markedly greater influence on condylar growth compared to other characteristics of occlusion.

4.3. Growth and Development

It is convenient to divide the craniofacial complex into four areas that grow rather differently:

(1) The cranial vault, the bones that cover the upper and outer surface of the brain;

(2) The cranial base, the bony floor under the brain, which also is the dividing line between the cranium and the face;

(3) The nasomaxillary complex, made up of the nose, maxilla, and associated small bones;

(4) The mandible.

4.4.1. The Cranial Vault

The cranial vault is made up of a number of flat bones that are formed directly by intramembranous bone formation, without cartilaginous precursors. From the time that ossification begins at a number of centers that foreshadow the eventual anatomic bony units, the growth process is entirely the result of periosteal activity at the surfaces of the bones. Remodeling and growth occur primarily at the periosteum-lined contact areas between adjacent skull bones, the *cranial 'sutures,* but periosteal activity also changes both the inner and outer surfaces of these plate-like bones (294).

4.4.2. The Cranial Base

The bones of the base of the cranial base are formed initially in cartilage and are later transformed by endochondral ossification to bone. This is particularly true of the midline structures. As one moves laterally, growth at sutures and surface remodeling become more important, but the cranial base is essentially a midline structure.

Early in embryonic life centers of ossification called synchondrosis appear. These important growth sites are between the sphenoid and occipital bones, or *spheno-occipital synchondrosis,* the *intersphenoid synchondrosis,* between two parts of the sphenoid bone, and the *spheno-ethmoidal synchondrosis,* between the sphenoid and ethmoid bones. Histologically, a synchondrosis looks like a two-sided epiphyseal plate. The area between the two bones consists of growing cartilage. The synchondrosis has an area of cellular hyperplasia in the center with bands of maturing cartilage cells extending in both directions, which will eventually be replaced by bone.

A significant difference from the bones of the extremities is that immovable joints develop between the bones of the cranial base, in considerable contrast to the highly movable joints of the extremities. The cranial base is thus rather like a single long bone, except that there are multiple epiphyseal plate-like synchondroses (294).

Björk (41) examined 243 individuals at the age of 12 and at the age of 20 in order to analyze the growth mechanism of the cranial base during the period of adolescence in Swedish boys. As a result, he reported that that the temporal bone, and hence the glenoid fossa, is displaced downward and forward or backward and upward as a result of the cranial base rotation and consequently brings about changes in the mandibular position. The direction of growth at the condyle will influence the general shape of the mandible. A more upward direction will increase the vertical height; a backward direction will increase the sagittal length. The size of the gonial angle will depend on the amount of condylar growth as well as on its direction in relation to the amount of appositional growth at the gonial angle.

The body of the maxilla increases in length toward the palatine bone and is lowered as a result of the growth which occurs between the palatine bone and the pterygoid processes. In the individual this lowering may be forward and downward or rearward and downward, a variation in the growth direction of the maxilla which is coordinated with the cranial base rotation and with the sutural growth of the upper facial structure During the period of adolescence, the relation between the nasion-sella line and the deepest median contour of the anterior cranial fossa remains noticeably constant, whereas tuberculum sellae and dorsum sellae appear to be raised in relation to the center of the sellae. For this reason, the n-s line appears to be particularly suitable as a reference line during the adolescent period in man. Its suitability as a reference line for investigations into earlier growth periods remains to be investigated.

Ngan et al (236) compared the skeletal growth changes between Class II Division 1 and Class I female subjects between ages 7 and 14. No significant difference was found in cranial base dimension between the Class I and Class II subjects. The largest growth occurred between 12 to 13 years. For both samples, maximum growth occurred in a downward and backward direction with reference to S-N, coincident with active growth at the spheno-occipital synchondrosis that was active through puberty.

Henneberke and Andersen compared (143) the growth of the cranial base in Dutch children between 7 to 14 years of age who had undergone orthodontic

treatment and children who had not. Growth changes of the cranial base (S-N, N-Ba, and S-Ba) were evaluated. No significant difference could be demonstrated between subjects who had received orthodontic treatment and subjects who had not. The cranial base displayed sexual dimorphism in the timing and amount of growth. All dimensions measured in girls were significantly smaller than in boys. No adolescent growth spurts were found in girls; boys showed adolescent growth spurts for S-N and N-Ba. Adolescent growth velocities were significantly greater for boys than for girls.

It has been reported that cranial base lengths did not increase in adults during intervals ranging from 5 to 13 years (64, 357).

4.4.3. Maxilla (Nasomaxillary Complex)

The maxilla develops postnatally entirely by intramembranous ossification. Since there is no cartilage replacement, growth occurs in two ways: (1) by apposition of bone at the sutures that connect the maxilla to the cranium and cranial base and (2) by surface remodeling. In contrast to the cranial vault, however, surface changes in the maxilla are quite dramatic and as important as changes at the sutures. The growth pattern of the face requires that it grow "out from under the cranium," which means that the maxilla must move through growth a considerable distance downward and forward relative to the cranium and cranial base. As the downward and forward movement occurs, the space that would otherwise open up at the sutures is filled in by proliferation of bone at these locations. The sutures remain the same width, and the various processes of the maxilla become longer. Bone apposition occurs on both sides of a suture, so the bones to which the maxilla is attached also become larger. Part of the posterior border of the maxilla is a free surface in the tuberosity region. Bone is added at this surface, creating additional space into which the primary and then the permanent molar teeth successively erupt.

As the maxilla grows downward and forward, its front surfaces are remodeled, and bone is removed from most of the anterior surface. The overall growth changes are the result of both a downward and forward translation of the maxilla and a

simultaneous surface remodeling. The whole bony nasomaxillary complex is moving downward and forward relative to the cranium, being translated in space (294).

Nanda (231) evaluated 40 individuals from the ages of 5 to 18. According to the linear measurement between sella and subspinale (S-A) the relative amount of increase during the entire 12-year period were 19 per cent. The pattern of increase in SNA for the total group showed very little change with age. During the 12 years of growth, this angle showed an increase of less than 1 degree.

İşeri and Solow (159) studied the sutural growth displacement of the maxilla between the ages of 8 and 21 years. The average forward displacement of the maxilla in relation to the anterior cranial base was 6 degrees from 8.5 to 17.5 years. The average path of displacement was inclined about 45 degrees in relation to the nasion-sella line from 8.5 to 14.5 years, and then changed to almost horizontal. Maxillary rotation occurred in the transverse plane. The timing of growth differed between the horizontal and vertical components of the maxillary growth translation. Horizontal displacement peaked at 11 and terminated at 18 years, whereas vertical displacement peaked at 12 and terminated at 15 years of age.

In the study of Ngan et al (236) the maxilla (S-IM-A) was found to be normally related to the cranial base in Class II subjects.

Ochoa and Nanda (241) followed 28 untreated subjects from ages 6 to 20 years and reported that SNA angle did not change significantly from ages 6 to 20. The changes in the angulation of the palatal plane were minimal.

Chung and Wong (71) evaluated 85 skeletal Class II untreated subjects with low, average and high mandibular plane angles at the ages of 9 and 18. Results showed that at age 9, significant differences were present between the high- and the low-angle male and female groups in SNA. This angle increased from ages 9 to 18 in all groups.

Baccetti et al (13) compared a group of 25 untreated subjects with Class II malocclusion in the deciduous dentition with a control group of 22 untreated subjects with ideal occlusion at the same dentitional stage. The subjects were monitored

during a 2-year period in the transition from the deciduous to the mixed dentition. During the period examined, cephalometric changes consisted of significantly greater maxillary growth increments and smaller increments in mandibular dimensions in the Class II sample.

4.4.4. Mandible

In contrast to the maxilla, both endochondral and periosteal activity are important in growth of the mandible.

Cartilage covers the surface of the mandibular condyle at the temporomandibular joint. Although this cartilage is not like the cartilage at an epiphyseal plate or a synchondrosis, hyperplasia, hypertrophy and endochondral replacement do occur there. All other areas of the mandible are formed and grow by direct surface apposition and remodeling.

As a growth site, the chin is almost inactive. It is translated downward and forward, as the actual growth occurs at the mandibular condyle and along the posterior surface of the ramus. The body of the mandible grows longer by periosteal apposition of bone on its posterior surface, while the ramus grows higher by endochondral replacement at the condyle accompanied by surface remodeling. Conceptually, it is correct to view the mandible as being translated downward and forward, while at the same time increasing in size by growing upward and backward. The translation occurs largely as the bone moves downward and forward along with the soft-tissues in which it is embedded.

The mandible grows longer by apposition of new bone on the posterior surface of the ramus. At the same time, large quantities of bone are removed from the anterior surface of the ramus. In essence, the body of the mandible grows longer as the ramus moves away from the chin, and this occurs by removal of bone from the anterior surface of the ramus and deposition of bone on the posterior surface.

In infancy, the ramus is located at about the spot where the primary first molar will erupt. Progressive posterior remodeling creates space for the second primary

molar and then for the sequential eruption of the permanent molar teeth. More often than not, however, this growth ceases before enough space has been created for eruption of the third permanent molar, which becomes impacted in the ramus (294).

Voudouris and Kuftinec (376) points out that significant anatomic differences between the condyle of the mandible and the epiphysis of long bones may permit greater modification of the condyle. The unique layer of fibrocartilage covering the condyle is absent in the epiphysis. In addition, compared with epiphyseal chondrocytes, condylar prechondroblasts are not surrounded by an intercellular matrix to isolate them from local factors. The chondrocytes are further oriented in a multidirectional fashion suitable for changes in growth direction in comparison to the columnar arrangement of the epiphyseal chondrocytes.

Ngan et al (236) reported that mandibular position (S-N-B and S-N-Pog) is significantly more retrusive in Class II when compared with Class I subjects. Mandibular length (Ar-Gn) and corpus length (Go-Gn) were found to be shorter in Class II subjects. Maxillo-mandibular difference (A-N-B) between Class I and II subjects was present at age 7 and persisted through puberty, maintaining a greater angle of convexity (A-N-Pg) in Class II subjects. These results suggest that Class II malocclusion can be detected early. The majority of the Class II cases showed mandibular skeletal retrusion or a combination of horizontal and vertical abnormalities of the mandible rather than maxillary protrusion.

Björk (42) investigated the mandibular growth rotation. According to him, from the standpoint of growth, the mandible may be regarded as a more or less unconstrained bone, for it may change its inclination in several ways. A critical factor in this respect is the site of the center of rotation, which may be located at the posterior or anterior ends of the bone or somewhere in between, in which case the ends of the mandible swing in different directions. There are various types of rotation.

Forward rotation may occur in the following three ways:

Type I. In this type (the one that is usually considered) there is a forward rotation about centers in the joints which gives rise to a deep-bite, in which the lower dental arch is pressed into the upper, resulting in underdevelopment of the anterior face height. The cause may be occlusal imbalance due to loss of teeth or powerful muscular pressure. This lowering of the bite may occur at any age.

Type II. Forward growth rotation of the mandible about a center located at the incisal edges of the lower anterior teeth is due to the combination of marked development of the posterior face height and normal increase in the anterior height. The posterior part of the mandible then rotates away from the maxilla.

Type III. In anomalous occlusion of the anterior teeth the forward rotation of the mandible with growth changes its character. In the case of large maxillary overjet or mandibular overjet, the center of rotation no longer lies at the incisors but is displaced backward in the dental arch, to the level of the premolars. In this type of rotation the anterior face height becomes underdeveloped when the posterior face height increases. The dental arches are pressed into each other and basal deep-bite develops.

In the growth rotation of Types II and III the mandibular symphysis swings forward to a marked degree and the chin becomes prominent. This is one of the reasons for the chin formation characteristic of man.

Backward rotation of the mandible is less frequent than forward rotation and two types have been recognized:

Type I. The center of the backward rotation lies in the temporomandibular joints. This is the case when the bite is raised by orthodontic means, by a change in the intercuspation or by a bite-raising appliance, and results in an increase in the anterior face height.

Backward rotation of the mandible about a center in the joints also occurs in connection with growth of the cranial base. In the case of flattening of the cranial base, the middle cranial fossa is raised in relation to the anterior one, and then the

mandible is also raised. There may be other causes also, such as an incomplete development in height of the middle cranial fossa, as in oxycephaly. This underdevelopment of the posterior face height leads to a backward rotation of the mandible, with overdevelopment of the anterior face height and possibly open-bite as a consequence. The mandible is, in principle, normal.

Type II. Backward rotation here occurs about a center situated at the most distal occluding molars. This occurs in connection with growth in the sagittal direction at the mandibular condyles. As the mandible grows in the direction of its length it is carried forward more than it is lowered in the face, and because of its attachment to muscles and ligaments it is rotated backward.

Hunter (156) reported that in both females and males, the anteroposterior length of the mandible exhibited the most consistent relationship with growth in height throughout adolescence. There was a relatively high correlation between the gain in length of the mandible and body height in the pubertal growth period. The anteroposterior length of the mandible was greater in males than in females at the onset of the pubertal growth period in height. During the adolescent period there was greater absolute growth and a greater rate of growth in males than females. This was attained in a shorter duration. From the end of pubertal growth period in height to the completion of mandibular growth, the males had a greater increase in length of the mandible over a longer period of time. The final mean length of the mandible was 122.3 mm in males and 106.6 mm in females. In the vast majority of males (88.3 %), a small amount of facial growth occurred after the skeletal age of eighteen and probably after skeletal maturation was complete.

The study of Baccetti et al (13) demonstrated that the skeletal pattern of Class II malocclusion in the deciduous dentition typically was characterized by significant mandibular skeletal retrusion and mandibular size deficiency. A greater downward and backward inclination of the condylar axis relative to the mandibular line, with consequent smaller decrements in the gonial angle, were found in the Class II group, an indication of posterior morphogenetic rotation of the mandible in patients with Class II malocclusion occurring during the period examined.

Nanda (231) reported that the relative amount of increase during the entire 12-year period was 24 per cent for S-B. This indicated that the mandible (lower face) had greater forward growth, resulting in a straighter facial profile. The progression of group means with age for angle SNB exhibited a gradual but slow increase throughout the 12 year period. On the basis of occlusion, the groups with normal occlusion had a slightly larger SNB and also showed a greater increase in this angle with age. This resulted in a more forward relation of the mandible to the cranial base in subjects with normal occlusion. The incremental pattern of the ANB angle with age for the total group means showed a gradual decrease in this angle with age.

Chung and Wong (71) reported the increase in SNB from ages 9 to 18. Point B grew more forward than did Point A with age. Thus, the skeletal Class II relationship tended to improve with age. In their study, all groups showed mandibular forward rotation with age. The low-angle groups had significantly more rotation than did the high-angle groups.

Ochoa and Nanda (241) showed that SNB angle increased significantly in the male subjects throughout life. ANB angle decreased continuously until age 14. The mandible grew in length twice as much as the maxilla from ages 6 to 20. The male sample overall developed 2 years longer than the female sample and also grew relatively more. With growth, the facial profile became straighter by increased prominence of the chin in the male sample. The female sample had less incremental growth and duration of growth of the mandible, so that the profiles remained more convex when compared with the male sample.

Nanda and Ghosh (232) performed a study of the growth pattern in sagittal linear measurements at points A, B, and pogonion relative to the pterygoid vertical plane in a Class I sample consisting of 86 subjects (46 males 40 females). Serial cephalometric radiographs were traced and digitized at ages 6, 12, 18, and 24 years. The results indicated that between the ages of 6 and 24 years there was a total growth increment of 6.07, 7.53, and 11.17 mm at points A, B, and pogonion, respectively, in the female Class I sample and 9.49, 11.65, and 16.21 mm at points A, B, and pogonion, respectively, in the male sample. Although the actual change in length of these measurements was larger in the male subjects than in the female subjects, in

terms of percentage of growth increment in each of these three measurements from age 6 to 24 years, the anterior movement at point B relative to point A, and at pogonion relative to points B and A was approximately the same for both male and female subjects.

Pollard and Mamandras (289) assessed maxillary and mandibular postpubertal growth changes of 39 male subjects when they were 16 and 20 years of age. The sample had no previous orthodontic treatment and exhibited Class II skeletal characteristics. Mean mandibular growth (Co-Gn) was approximately three times that of maxillary growth (Co-A). Total mandibular growth observed between 16 to 20 years of age was approximately 4.3 mm. The mandible appeared to rotate anteriorly superiorly, reflected by a mean reduction in mandibular plane angle of 1.47 ° and a greater increase in posterior versus anterior face height. There were not statistically significant changes in incisor angulation. Mean growth changes in this Class II sample were comparable to those previously reported for male subjects with Class I malocclusions over the same age period, suggesting a similarity in postpubertal development between these two groups.

Love et al (196) examined postpubertal craniofacial skeletal and dental changes of 30 male subjects with no previous orthodontic treatment who had Class I skeletal and dental characteristics. Lateral cephalograms were taken when subjects were 16, 18, and 20 years of age. Mandibular growth was found to be statistically significant for the age periods of 16 to 18 years and 18 to 20 years. Growth from 16 to 18 years was greater than that from 18 to 20 years. Maxillary and mandibular growths were highly correlated at each age period. However, overall mandibular growth was approximately twice that of overall maxillary growth. Mandibular growth was found to involve an upward and forward rotation, a result of posterior vertical growth exceeding anterior vertical growth. Lower incisors were found to tip lingually with increasing age.

Bishara (31) compared the changes in mandibular length in untreated and treated Class II Division 1 subjects from deciduous to permanent dentition. The differences in mandibular length and position were more evident in the early stages of development than at later stages. Longitudinal comparisons of growth profiles

indicated that the growth trends were essentially similar between the untreated Class II/1 and normal subjects in the various parameters compared. The comparisons of growth magnitude indicated the presence of greater skeletal facial convexity in the untreated Class II/1 subjects, accompanied by a tendency for a more retruded mandible. Initial comparisons between the Class II/1 treated groups and normal subjects indicated that the Class II/1 malocclusions were associated with a larger overjet, deeper overbite, and greater ANB angle.

Lewis and Roche (194) followed 20 untreated subjects of 17 or 18 years of age for about three decades. The maximum values for the cranial base and mandibular lengths within individuals occurred between 29 and 39 years.

4.4. Treatment Modalities of Class II Division 1 Malocclusions

4.5.1. Treatment Approaches to Dental Class II Malocclusions

The most common Class II malocclusion is one that is caused by an underlying Class II skeletal discrepancy. The Class II malocclusion that is present in an individual with a normal skeletal jaw relationship is less frequent and caused by forward movement during dental development of the maxillary molars relative to the mandibular molars. This less common condition may be unilateral or bilateral in presentation. There are two alternatives for treatment of the dental Class II malocclusion: a nonextraction approach involving distal movement of the maxillary teeth and the extraction approach involving unilateral or bilateral dental extractions (35).

4.4.1.1. Extraction vs. Nonextraction Treatment

If the Class II dental relationship is the result of mesial drift of maxillary permanent molars caused by premature loss or small maxillary primary molars, it may be possible to move the maxillary permanent molars distally to achieve a normal Class I relationship and regain space for the other permanent maxillary teeth.

Successful distal movement of the molars depends on the severity of the mesial drift. If the molars are tipped forward, their crowns can be moved distally using either extraoral force applied to the molars with a headgear or an intraoral spring force applied with a removable or fixed appliance. If the roots as well as the crowns of the molars are forward, often caused by loss of second primary molars before eruption of the permanent molars, it is a much more difficult challenge for the clinician. This circumstance requires distal bodily molar movement that usually is possible only with full-time headgear wear. Appliances that generate an intraoral distal force to the molars must be dependent on anterior anchorage to prevent anterior movement of the maxillary anterior teeth as a side effect. Usually the magnitude and duration of force necessary to bodily move the molars distally overwhelm the anterior anchorage and result in unacceptable protraction of maxillary incisors.

A more practical approach to treatment of the dental malocclusion, characterized by maxillary molars with their roots and crowns mesially positioned in a Class II relationship, is to accept the molar relationship and obtain space for the remaining maxillary teeth by extracting maxillary first or second premolars (35).

4.5.2. Treatment Approaches to Skeletal Class II Malocclusions

Depending on the diagnosis, there are three alternatives for treating any skeletal problem (35, 253):

(1) growth modification,
(2) dental camouflage,
(3) orthognathic surgery.

In the growing child, all three may be possible, whereas in the adult, only the latter two are options.

4.5.2.1. Growth Modification

The goal of growth modification is to alter the unacceptable skeletal relationships by modifying the patient's remaining facial growth to favorably change the size or position of the jaws. Basically, three types of orthodontic appliances are used for growth modification of Class II skeletal problems: extraoral force appliances, functional appliances, and interarch elastic traction (35).

4.5.2.1.1. Extraoral Force (Headgear) Appliances

A headgear intended for use in growth modification is designed to deliver an adequate extraoral orthopedic force to compress the maxillary sutures, modifying the pattern of bone apposition at these sites. Although posterior and superior extraoral orthopedic forces primarily are intended to inhibit anterior and inferior development of the maxilla, they also inhibit mesial and occlusal eruption of the maxillary posterior teeth. The goal of treatment is for this restriction of maxillary growth to occur while the mandible continues to grow forward an adequate amount to "catch up" with the maxilla (35, 296).

Although the headgear can be an effective appliance in the treatment of a variety of Class II problems, the most ideal indication for the use of extraoral force in the correction of skeletal Class II malocclusions is with anteroposterior maxillary excess. Because the headgear is intended to restrict anterior and inferior maxillary growth while growth in other areas progresses, the maxillary anteroposterior excess (maxillary protrusion) would seem to be the most suitable skeletal problem for treatment in this manner. Another optimum indication for treatment with headgear accompanying the maxillary excess would be normal mandibular skeletal and dental morphology because the extraoral force would minimally influence these features. Finally, the ideal circumstance for use of headgear must be one where there is continued active mandibular growth, primarily displacing the mandible in a forward, rather than downward direction (35).

There are essentially two types of headgear available for delivering extraoral force to the maxilla: the facebow and the J-hook headgear. The first and most common type of headgear is the facebow, which is a large-gauge wire framework

consisting of an outer bow for the extraoral attachment soldered to an inner bow that attaches intraorally in tubes attached to the maxillary first permanent molar bands. The second type of headgear, commonly referred to as a *J-hook headgear,* is two separate, curved, large gauge wires that are formed on their ends into small hooks, both of which attach directly to the anterior part of the maxillary arch wire. This type of headgear is more commonly used for retraction of canines or incisors rather than orthopedic purposes (35).

There are two basic types of extraoral attachments that provide anchorage for the headgear. The first is the cervical attachment or neck strap. Because the point of attachment is usually below the occlusal plane, the extraoral force is directed inferiorly as well as posteriorly. This force vector may help anteroposterior correction but may amplify vertical maxillary excess problems. With the facebow the cervical attachment creates an extrusive and distal force to the maxillary molars.

The second type of extraoral anchorage for a headgear is the occipital attachment or headcap. With the point of attachment well above the occlusal plane, the extraoral force is directed superiorly and posteriorly. This high attachment permits the creation of a force vector that contributes to correction of not only anteroposterior maxillary excess, but also to vertical maxillary excess. The higher angle of the force vector created results in a distal and intrusive force to the maxillary molars.

It is possible to use a combination of the cervical and occipital attachments, termed combination headgear, to distribute the external force over more surfaces and to provide a convenient means of modifying the direction of the force vector (35).

In a preadolescent child, headgear should be worn regularly for at least 10 to 12 hours per day to be effective in controlling growth. The growth hormone release that occurs in the early evening strongly suggests that, as with functional appliances, putting the headgear on right after dinner and wearing it until the next morning—not waiting until bed time to put it on—is an ideal schedule. The current recommendation is a force of 12 to 16 ounces (350 to 450 g) per side. When teeth are used as the point of force application, some dental as well as skeletal effects must be

expected. Extremely heavy forces (greater than 1000 g total) are unnecessarily traumatic to the teeth and their supporting structures, while lighter forces may produce dental but not skeletal changes (293).

Baumrind et al (25) have demonstrated that distal molar movement is a significant contributing factor to downward projection of mandibular growth during headgear treatment. Downward movement of either the jaw or the teeth tends to project mandibular growth more vertically, which nullifies most of the forward mandibular growth that reduces the Class II relationship.

Some authors claim that headgear therapy causes skeletal maxillary changes in humans (22), but others deny its effects (29, 45, 161, 180).

In the literature it was reported that cervical headgear therapy causes significant extrusion of the molars that might result in an increased lower facial height (23, 24, 25, 291). However, the high-pull headgear produces, in addition, an intrusive component instead of an extrusive one. Furthermore, with the highpull headgear, it is possible to change the direction of force in relation to the center of resistance of the dental units to which the force is being applied, to achieve better control of the resulting tooth movement (24, 291, 342, 382).

In 1978 Melsen (215) performed an implant study about the effects of cervical anchorage during and after treatment. Two groups of ten patients with postnormal molar relation, identical as regards facial morphology and dental stage, were treated for 8 months with cervical traction of the Kloehn type. The extraoral arch of the headgear was tilted upward in relation to the occlusal plane in one group and downward in the other. The local tooth movements were measured and related to metal implants inserted in the jaws. The movement of the implants in relation to the anterior cranial base expressed the amount and direction of the sutural and condylar growth. It was shown that a normal molar relationship was established in the shortest time with a downward tilt of the extraoral bow. A pronounced distal tipping of the molars was observed in these patients. The growth direction of the maxilla during cervical treatment was downward and backward and the mandible rotated posteriorly. The children were observed again 7 to 8 years after treatment, and it

appeared that the influence of the headgear on the growth pattern of the facial skeleton was reversible, as a pronounced anterior direction of growth of the maxilla as well as of the mandible was observed in all but two subjects.

Hubbard et al (155) evaluated the effects of orthodontic treatment with the use of the cervical pull facebow headgear in 85 patients with Class II malocclusions. The results showed that the changes were very close to what would occur as a result of normal growth in Class I individuals. The maxillary permanent first molars continued to progress forward, the maxilla continued to grow forward, and the cranial base showed very little change, if any. The mandibular plane angle did not increase appreciably with treatment, regardless of the size of the pretreatment mandibular plane angle.

Firouz et al (101) examined the skeletal and dental effects of the high-pull extraoral appliance, when the resultant force was directed through the level of trifurcation of the maxillary molars on twelve adolescent patients with Class II, Division 1 malocclusions. Each patient wore the headgear for a 6-month period, an average of 12 hours a day. The data indicated that by directing the force of the headgear approximately through the center of resistance of the maxillary molars, it is possible to accomplish simultaneously a substantial distal movement of the molars (2.6 ± 0.6 mm), as well as significant intrusion (0.54 ± 0.54 mm). In addition, the results demonstrated that the applied force of 500 g was sufficient to initiate maxillary orthopedic changes in the treated patients. These changes included relative restriction of horizontal and vertical maxillary growth, as well as distal movement (mean: 0.8 mm) of the maxillary anterior border in the treatment group relative to an untreated control group.

Üçem and Yüksel (368) compared different vectors of forces applied by combined headgear. The study material consisted of 30 patients with Class II dental relationships and steep mandibular plane angles. Three groups of 10 patients each were formed. In the first treatment group, forces of 150 g per side were used for the high-pull component and the cervical component. In the second treatment group, forces of 200 g per side for the high-pull component and 100 g per side for the cervical component were applied. In the third treatment group, forces of 100 g per

side were applied for the high-pull component and 200 g per side for the cervical component. Distal tipping of upper molar was greatest in the third treatment group. Intrusion of the upper molar in the second treatment group and extrusion of the upper molar in the third treatment group were statistically significant. Changes in occlusal and mandibular plane angles showed significant differences between the groups.

Combining extraoral force and a functional appliance has also been recommended as a means of reducing vertical and sagittal maxillary displacement, achieving autorotation, and increasing forward displacement of the mandible (360, 361).

Lagerström et al (186) examined dental and skeletal changes in patients treated with the high-pull headgear-activator combination. A group of 40 consecutively treated subjects with a Class II molar relationship and a minimum of 5 mm overjet was used for this study. The results showed that Class II correction often was achieved by distal repositioning of the maxillary teeth and mesial repositioning of the mandibular teeth with a wide range of variation. Correlation of maxillary molar repositioning with total interarch occlusal change showed a positive relationship; however, a weak correlation suggested that other variables were contributing factors, in addition to distal upper molar positioning. The change in mandibular molar position compared with the movement of pogonion strongly suggests that forward growth of the mandible is important to the correction of the Class II malocclusion. When total molar repositioning in the upper jaw was correlated with total molar repositioning in the lower jaw, a strong inverse correlation was found, indicating that upper molar movement parallels lower molar movement.

Lehman et al (192) treated 23 actively growing patients with Class II, Division 1 malocclusions with a combination headgear-activator. At the end of active treatment, overjet and convexity were decreased in all patients. The five-year, post-treatment cephalograms indicated relapse of the Class II, Division 1 malocclusion in 4 patients (17%), and maintenance of the correction in 19 patients (83%). The treatment results appeared to be related to rotation of the *y*-axis. Patients with relapse demonstrated posterior rotation of the *y*-axis during and after treatment, while patients with mandibular incisor crowding, showed anterior rotation of the *y*-axis during and after

treatment. The direction of rotation of the *y*-axis did not change in any of the patients when treatment and post-treatment periods were compared.

4.5.2.1.2. Functional Appliances

The history of the functional appliance can be traced back to 1879, when Norman W. Kingsley introduced the 'bite-jumping' appliance (179). Kingsley's removable plate with molar clasps might be considered the prototype of functional appliances. As he described it, 'The object was not to protrude the lower teeth, but to change or jump the bite in the case of an excessively retreating lower jaw.' Wilhelm Roux is credited as the first to study the influences of natural forces and functional stimulation on form in 1895 (312). His work became the foundation of both general orthopedic and functional dental orthopedic principles. Later, Karl Häupl saw the potential of Roux's hypothesis and explained how functional appliances work through the activity of the orofacial muscles (122). The first practitioner to use functional jaw orthopedics to treat a malocclusion was Pierre Robin in 1902 (306). Robin designed his monobloc specifically for children with the glossopitosis syndrome. His appliance influenced muscular activity by changing the spatial relationship of the jaws.

In 1909, at the International Dental Congress in Berlin, Emil Herbst (144) introduced a fixed pin and tube appliance to posture the mandible forward.

Alfred P. Rogers (1873-1959), sometimes called the father of myofunctional therapy, also recognized the importance of the whole orofacial system. In addition, he was a strong proponent of the total-child approach and advocated muscular exercises to improve neck, head, tongue posture and encourage nose breathing. Although most of his exercise has become osolete, Rogers was the first to implicate the facial muscles for the growth, development, and form of the stomatognathic system (378).

In 1909, Viggo Andresen removed his daughter's fixed appliances before she went away to camp over the summer and placed a modified Hawley-type retainer on the maxillary arch. However, he added a lingual horseshoe flange that guided the mandible 3 to 4 mm forward when the teeth were brought into maximal closure

allowed by the interposed acrylic guide plane. This was done to prevent any relapse over the 3-month vacation period. On his daughter's return, Andresen was surprised to see nighttime wearing of the appliance not only had eliminated the abnormal neuromuscular compensations but also had produced a complete sagittal correction and significantly improved the facial profile. The result was stable. Applying this technique to other patients resulted in significant sagittal corrections that he could not produce with conventional fixed appliances (6, 7, 8, 9).

In designing an inert appliance that fitted loosely in the mouth and, because of its mobility, transferred muscular stimuli to the teeth, jaws, and supporting structures, Andresen had taken a decisive step in orthodontic treatment. Although he had effectively redesigned Robin's monobloc to correct Class II Division 1 malocclusions, he declared that he had no knowledge of Robin's work at the time.

The original name Andresen used for this type of treatment was *biomechanical orthodontics.* Only later, after teaming up with Karl Häupl and doing further work on concepts and technique refinements, was the name changed to *functional jaw orthopedics,* which was more descriptive (8, 123).

In 1925, Andresen, then director of the orthodontic department at the University of Oslo, began developing for the government a simple method of treating Norwegian children. He modified his retainer into an orthodontic appliance, using a wax bite to register the mandible in an advanced position.

At the university, Karl Häupl (1893-1960), an Austrian pathologist and periodontist, saw the possibilities of the appliance and became an enthusiastic advocate of what he and Andresen called the "Norwegian system." Häupl's theories were inadvertently strengthened by the findings of Oppenheim, who showed the potential tissue damage caused by the heavy orthodontic forces of fixed appliances. At that time, there was no mention of "growth stimulation."

Activator use became so widespread among European practitioners that there was concern that proper diagnosis was being neglected (151). Unfortunately, reminiscent of Angle's following, "functional jaw orthopedics became a profession of faith, a religion, beside which no other opinion was tolerated." Furthermore,

Reitan, in his 1952 doctoral thesis, questioned Roux's hypothesis and demonstrated that no special histologic picture emerged from the use of functional appliances. His findings were supported by later researchers.

Andresen and Häupl later collaborated on a textbook (*Funktionskieferorthopädie*) about their system in 1936. The sixth edition included Leopold Petrik as coauthor. Although Häupl's complete rejection of fixed appliances led the profession astray for a time, had it not been for his promotional efforts, the activator might have languished in obscurity.

In 1950, Wilhelm Balters (1893-1973), in an effort to treat Class II malocclusions characterized by deficient mandibles, began to modify Andresen's activator. He gave it the name *bionator.* It is indicated for patients with favorable facial growth patterns and is designed to produce forward positioning of the mandible. As with the function regulator, the bionator is available in 3 designs. Consisting of 2 halves connected by a Coffin spring, it is less restrictive of speech than Andresen's appliance. However, the treatment also highly depends on patient compliance, especially with regard to exercising (214).

A more recent innovation in functional appliance design, the functional corrector (or functional regulator), was developed by Rolf Frankel (110) in Germany and was introduced in 1966. This appliance was unique in that it was principally tissue-borne, mostly supported in the vestibule rather than supported by the teeth. Countless modifications of these removable functional appliances followed their introduction. The individuals who made the modifications usually renamed the appliance, more often than not, with their own name. All of these appliances postured the mandible downward and forward with the intent that the muscle and soft-tissue pressure attempting to reposition the jaw back to its original position would modify jaw growth to correct the Class II skeletal problem. The appliance needs to be worn an adequate length of time during a period of active mandibular growth to have a positive prognosis (35).

The theoretical basis of functional treatment in general is the principle that a "new pattern of function," dictated by the appliance, leads to the development of a

correspondingly "new morphologic pattern." The "new pattern of function" can refer to different functional components of the orofacial system-for example, the tongue, the lips, the facial and masticatory muscles, the ligaments, and the periosteum. Depending on the type of appliance, its proponent puts more emphasis on one of these different functional components. The "new morphologic pattern" includes a different arrangement of the teeth within the jaws, an improvement of the occlusion, and an altered relation of the jaws. It also includes changes in the amount and direction of growth of the jaws, and differences in the facial size and proportions (63).

The ideal indication for the use of the appliance in the correction of skeletal Class II malocclusions is a mandibular deficiency. Another ideal circumstance for treatment with a functional appliance, in addition to the mandibular deficiency and normal maxillary development, is a normal or mildly decreased face height because, theoretically, most of these appliances encourage mandibular posterior dental eruption. An additional optimal indication for functional appliances is slightly protrusive maxillary incisors and slightly retrusive mandibular incisors because the expected dental effect of these appliances includes some maxillary incisor retraction and mandibular incisor protraction. Finally, as with headgear therapy, the ideal patient must have active mandibular growth, primarily in a forward direction (35).

The literature suggests that functional appliances are most successful in cases with an overjet of up to 11 mm, an increased overbite, active facial growth, and good cooperation (20).

In functional appliance treatment, the position of the chin is affected by the following mechanisms: (1) mandibular condylar remodeling, (2) glenoid fossa remodeling, (3) condylar position changes within the fossa, and (4) mandibular autorotation (264).

4.5.2.1.2.1. How Do Functional Appliances Stimulate the Condylar Growth?

Voudouris and Kuftinec asked "Can we aid in the growth of condyles to a clinically significant degree?" and tried to find the answer in their study (376). This commonly asked question must always be qualified in terms of time before being answered intelligently. This is because the clinically significant results of short-term treatment (383) have been shown to be quite different from the findings on long-term stability (384).

Over the years, several theories have emerged attempting to shed light on condylar growth. One of the earliest theories, the *genetic* theory, suggests the condyle is under strong genetic control like an epiphysis that causes the entire mandible to grow downward and forward (205). Although this may be related more to development of the prenatal than postnatal condyle, the theory does indirectly question the effectiveness of orthopedic appliances in condylar growth as proposed by Brodie (53). Several long-term investigations actually showed clinically insignificant condylar growth modification after continuous mandibular advancement with a reasonable retention period in human beings (250, 262) although the initial treatment results appeared encouraging (244). This leads to the conclusion that the general growth of the condyle appears relatively unalterable in long-term studies. In contrast, one similar study of primates showed significant condylar growth modifications over the long-term but only after retention periods that were far too long to be feasible for human beings (211).

A second hypothesis (284, 288) based on the earliest available acute and blind EMG monitoring technique, suggests that hyperactivity of the lateral pterygoid muscles (LPM) promotes condylar growth. Rees (302) reported that other muscles and tendons, including those of the deep masseter and temporalis, also attach to the articular disk region. Attachments of the LPM to the condylar head or articular disk may be expected to cause condylar growth, but anatomic research has not found evidence that significant attachments actually exist. More recently, permanently implanted longitudinal muscle monitoring techniques have found that the condylar growth is actually related to decreased postural and functional LPM activity (337, 338).

This notion was also supported in human studies by Auf der Maur (12), Pancherz and Anehus-Pancherz (255), and Ingervall and Bitsanis (158) that reported decreased muscle activity.

A third hypothesis, the *functional matrix* theory, postulates the principal control of bone growth is not the bone itself, but rather the growth of soft-tissues directly associated with it (222, 223, 224, 225). Although this was supported in part by investigations testing the different growth and developmental responses between the condyle and epiphysis, there has been no explanation as to exactly how condylar growth would be stimulated. Thus, this theory's validity has been questioned (171). One of the reasons was that there was little explanation of the specific mechanism by which the condyle was stimulated to grow. Enlow and Hans (99) presented an excellent overall perspective suggesting that mandibular growth is a composite of regional forces and functional agents of growth control that interact in response to specific extracondylar activating signals.

Another hypothesis, the growth relativity, was suggested by Voudouris and Kuftinec (376). The glenoid fossa promotes condylar growth with the use of orthopedic mandibular advancement therapy. Initially, that displacement affects the fibrocartilaginous lining in the glenoid fossa to induce bone formation locally. This is followed by the stretch of nonmuscular viscoelastic tissues. Third and the most interesting aspect is the new bone formation some distance from the actual retrodiskal tissue attachments in the fossa. The glenoid fossa and the displaced condyle are both influenced by the articular disk, fibrous capsule, and synovium, which are contiguous, anatomically and functionally, with the viscoelastic tissues. Therefore, condylar growth is affected by viscoelastic tissue forces via attachment of the fibrocartilage that blankets the head of the condyle.

Although there is an extensive diversity of different functional appliances, they can be divided conveniently into three types: removable tooth-borne, removable tissue-borne and fixed tooth-borne (35).

4.5.2.1.2.2. Removable Tooth-borne Functional Appliances

This group includes activator, bionator, and twin block appliances. To achieve the desired skeletal and dental effects, these appliances depend on the stretch of the soft-tissues caused by the mandible being positioned downward and forward as well as by the muscle activity generated by the mandible attempting to return to its original position.

4.5.2.1.2.2.1. Activator

The original functional appliance design was a block of plastic covering the teeth of both arches and the palate, made to fit loosely, advance the mandible several millimeters for Class II correction, and open the bite 3-4 mm. In addition to their effects on jaw growth, these essentially passive appliances can tip anterior teeth and control eruption of teeth to alter vertical dental relationships. The original design had facets or flutes trimmed into the body of the appliance to direct erupting posterior teeth mesially or distally, so despite the simple design, dental relationships in all three planes of space could be changed. In current activator designs, flutes are replaced by a plastic shelf to impede eruption of upper posterior teeth while allowing eruption of lower posterior teeth, and lower incisors are capped to control forward displacement of the lower arch (297).

Most authors agree on the influence of the activator upon the dentoalveolar area (1, 248, 385). The orthopedic effect of the appliance, however, is a controversial topic of discussion. Some authors state that the skeletal effect of activator therapy is confined to a restriction of maxillary growth (1, 138, 139, 248), whereas others are of the opinion that the activator stimulates condylar, and thus mandibular, growth (30, 162, 371). An influence of activator treatment on the glenoid fossa has also been reported (30, 162, 371).

4.5.2.1.2.2.2. Bionator

Originated by Balters and sometimes still bearing his name, the bionator is best described briefly as a cut-down activator. Palatal coverage is eliminated. As with the

activator, lingual flanges stimulate forward posturing of the mandible and shelves or blocks between the teeth provide vertical control (297).

There is a much smaller mandibular lingual flange, minimal interocclusal acrylic, a transpalatal wire in place of palatal acrylic, and a modified labial bow with buccal extensions that minimize cheek pressure on the teeth (35).

Most studies dealt with short-term outcomes of Bionator therapy by using various types of control groups (untreated Class I or Class II subjects) (47, 157, 202). Dentoalveolar changes consist of maxillary incisor retraction and uprighting, associated with proclination of the lower incisors (when capping of these teeth is not used). An increase in mandibular molar eruption caused by adjustments in the eruption facets of the appliance has been documented as well. Although no skeletal modification has been found for the maxilla, a favorable increase in total mandibular length has been described consistently in patients treated with the Bionator. The skeletal changes are associated with significant effects on the soft-tissues, mainly consisting of changes in the vertical dimensions of the face and position of the lips (189, 221).

A long-term study on the craniofacial changes induced by the Bionator was done by Rudzki-Janson and Noachtar (313), who evaluated a group of patients treated with the Bionator five years after the completion of retention. These patients showed an increase in the size of the mandible and a decrease in both the distal skeletal jaw relationship and the gonial angle.

In a more recent long-term study Faltin et al (100) investigated the long-term effects and optimal timing for Class-II treatment with the Bionator appliance. Lateral cephalograms of 23 Class-II patients treated with the Bionator were analyzed. The findings of the study on Bionator therapy followed by fixed appliances indicated that this treatment protocol is more effective and stable when it is performed during the pubertal growth spurt. In the long term, the amount of significant supplementary elongation of the mandible in subjects treated during the pubertal peak is 5.1 mm more than in the controls, and it is associated with a backward direction of condylar growth. Significant increments in mandibular ramus height also were recorded.

4.5.2.1.2.2.3. Twin Block

This appliance was introduced by a Scottish orthodontist, William Clark (72), in 1977 as a two-piece or split activator using separate maxillary and mandibular appliances with occlusal acrylic portions that serve as inclined guide planes and bite blocks to determine the extent that the mandible is postured downward and forward. Although this appliance provides for more range of mandibular movement and is adjusted and modified more easily than other functional appliances, it has a greater tendency to protract mandibular incisors. The twin block appliance also can have active components incorporated similar to the other removable tooth borne functional appliances (35).

The appliance has the advantage of allowing nearly a full range of mandibular movement, easy acclimation and reasonable speech, so that it can be worn most of the time. The greatest disadvantage is that displacement of incisors can occur freely despite the absence of active springs or screws (297).

The Twin Block Appliance has been described by patients as being comfortable to wear (73). It can give good results relatively quickly, depending on patient cooperation, and has been considered to be advantageous when compared with other types of functional appliances (157). It is perhaps for these reasons that this appliance has become a popular choice of corrective appliance for growth guidance in Class II Division 1 malocclusion (66). This appliance is the most popular functional appliance in the United Kingdom (120).

In the literature, the mandible has been putatively shown to increase in length and height following Twin-block treatment (157, 364), but there is equal evidence against this hypothesis (393).

4.5.2.1.2.3. Removable Tissue-borne Functional Appliances

This type of functional appliance is represented by only one appliance named the *functional corrector or functional regulator* by its German developer, Rolf Frankel, this appliance was created in an attempt to minimize unwanted tooth movement and

to recontour the facial soft-tissue adjacent to the teeth as well as posture the mandible downward and forward (111). A mandibular lingual acrylic flange positions the mandible forward, whereas mandibular labial acrylic lip pads and large acrylic buccal shields hold the lip and cheek pressure away from the teeth and provide soft-tissue support for the appliance. These acrylic components are held together with a wire framework that includes a labial bow and transpalatal wire. Although the appliance is largely supported in the vestibular areas by means of the acrylic components, there still is some contact with the dentition, including wire rests occlusal to the maxillary molars to minimize their eruption, wires lingual to the mandibular incisors, and the labial bow.

With the FR-2, correction of Class II malocclusion is achieved by advancing the mandible with muscular training (112). Much research has been conducted to evaluate the effectiveness of the FR-2 appliance. It consistently has been shown to correct a Class II malocclusion, but the nature of its effect has been debated widely. Some controversial claims in various studies include that the FR-2 does not produce a significant skeletal change (69, 129, 233), it significantly restricts maxillary growth (86), and it primarily induces a significant increase in mandibular length (3, 86).

Few investigations, however, have followed the stability of this treatment protocol over a long term (282). In 2009 Freeman et al (114) evaluated the long-term effectiveness in a group treated with the FR-2 appliance of Frankel compared with an untreated Class II control group. The study suggested that correction of a Class II malocclusion with the FR-2 appliance maintains favorable results over the long term with both skeletal and dentoalveolar changes.

When weighting up the pro and cons of classical removable functional treatment by means of Activator, Bionator, etc. on one hand and fixed functional treatment by means of mandibular advancement mechanics on the other hand; the following disadvantages of removable functional appliances must be borne in mind (335):

(1) Being removable means compliance problems,

(2) Missing of the oral functions such as chewing, phonetics, senses of touch when incorporated,

(3) Muscles are stressed isometrically rather than isotonically,

(4) Their effects cannot be predicted,

(5) Difficulty in combining functional with fixed appliances,

(6) Discomfort in wearing and long treatment time.

4.5.2.1.2.4. Fixed Tooth-borne Functional Appliances

Fixed functional appliances have the advantage of not relying on patient compliance because they are fixed in the mouth, thus always working, and they can be used concurrently with full fixed appliances. They apply expansion instead of compression forces and force vectors run along the y axis. The point of force application can be adjusted by segmental arches. Gentle continuous force 24 hours a day can be applied (335). One significant disadvantage is that they are more prone to breakage than their removable counterparts (381).

Unlike removable bite jumping appliances, fixed functional appliances can be used successfully in the following instances (244, 249):

Post adolescent patients. Neglected patients who have passed maximal pubertal growth may be too old for functional appliances, as treatment with these appliances is extended over a long time period (2 to 3 years). Treatment with the Herbst appliance, on the other hand, can be finished within 6 to 8 months, thus making it possible to use the residual growth left in these older patients.

Mouth breathers. Nasal airway obstructions can make the proper use of removable appliances impossible, while this does not interfere with the correct function of the Herbst appliance.

Uncooperative patients. The Herbst appliance is fixed to the teeth and works continuously 24 hours a day without any assistance from the patient.

The benefits of using a fixed functional appliance include the 24-hour growth stimulus, but there are other, more important factors (268):

- Immediate alteration of profile, smile and facial expressions that helps to improve psychologic problems.
- Improvement of skeletal disharmony.
- Periodontal problems caused by deep overbite can be prevented.
- Traumatic injuries on upper incisors have less opportunity to occur.
- Sucking habits immediately disappear.
- Labial competence is established and mastication is improved.
- Oropharyngeal space is increased, as well as space for the tongue.
- Functional problems like mouth breathing and speech difficulties are improved.

There are also some contra-indications of fixed-functional treatment protocol (168, 213):

- Cases predisposed to root resorption.
- Dental and skeletal open bites.
- Vertical growth with high mandibular plane angle and excess lower facial height.
- Minimum buccal vestibular space.

Fixed functional appliances include the Herbst and its modifications.

4.5.2.1.2.4.1. Herbst Appliance

The Herbst appliance is a fixed bite-jumping device for treatment of Class II malocclusion. The appliance has several advantages when compared to removable bite-jumping appliances (functional appliances), such as the activator, bionator, and Frankel appliance: (1) The Herbst appliance works 24 hours a day, (2) no cooperation from the patient is required, and (3) treatment time is short (approximately 6 to 8 months) (249).

The appliance was originally introduced by a German professor, Emil Herbst (1842-1917), at the International Dental Congress in 1909, but his findings were not

published until 1934. In 1934 Herbst presented a series of articles in the Zahnärztliche Rundschau on his experiences with the appliance (144). The appliance kept the mandible in a continuous protruded position both during jaw closure and when the teeth were not in occlusion; for example, all function (speech, chewing, swallowing) was performed with the mandible in an anterior jumped position. Herbst claimed that condylar growth could be stimulated by his method of treatment, but no real proof could be presented. After 1934, however, very little was published on the subject, and the treatment method was more or less forgotten.

In the October, 1979, issue of the American Journal of Orthodontics Hans Pancherz reintroduced the Herbst appliance and called attention to the possibilities of stimulating mandibular growth by means of this appliance (244). It has gained increased popularity worldwide since that time. In lots of articles the effects of the appliance on the dentofacial complex (246, 247, 257) and on the masticatory system (256) were evaluated. Recently the Herbst treatment method has gained increasing interest, especially in Europe and in the United States, and several clinical and scientific articles have been published on the subject (92, 152, 153, 190, 208, 369).

Original Appliance design **(banded Herbst design).** The Herbst appliance is a fixed appliance and works as an artificial joint between the maxilla and the mandible. A telescope mechanism on either side of the jaws attached to bands on maxillary permanent first molars and mandibular permanent first premolars keeps the mandible in a continuous anterior jumped position. Each telescope consists of a tube and a plunger which fit together. The tube is attached to the maxillary molar band and the plunger to the mandibular premolar band. The tube and plunger are attached to their respective bands with screws and can freely rotate around their point of attachment. The length of the tube determines the amount of anterior bite jumping. The length of the plunger is adjusted to the length of the tube. If the plunger is too long, it protrudes behind the tube distally to the maxillary permanent first molar and may thus injure the buccal mucosa. If the plunger is too short, on the other hand, it may slip out of the tube when the mouth is opened wide. Besides opening movements, small lateral movements of the mandible can be performed with the Herbst appliance. This is possible because of a loose fit of the tube and plunger at their sites

of attachment. The mechanism permits vertical opening movements and, when properly constructed, also lateral movements of the mandible. In construction of the appliance, the overjet determines the amount of anterior bite jumping and the overbite determines the amount of vertical bite opening (244, 249).

The anchorage system of the Herbst appliance consists basically of the following: In the maxillary dental arch the first premolars and the permanent first molars are banded and are interconnected on each side with a half-round (1.5 x 0.75 mm) lingual or buccal sectional arch wire. In the mandibular dental arch the first premolars are banded and connected with a half-round (1.5 x 0.75 mm) lingual sectional arch wire touching the lingual surfaces of the front teeth. This form of anchorage is called *partial anchorage*. In several instances this type of anchorage is insufficient and is therefore increased by the incorporation of additional dental units: In the maxillary dental arch a labial arch wire is ligated to brackets on the first premolars, canines, and incisors. In the mandibular dental arch the lingual sectional arch wire is extended to the permanent first molars which, therefore, also are banded. This form of anchorage is called *total anchorage* (249).

Although the telescoping mechanism essentially is identical in all Herbst designs, many variations in overall composition are possible from one design to another.

Other types of Herbst mechanisms are *cast splint* (383), *acrylic splint* (212, 386), and *stainless steel crowns* (91, 121).

Cast Splint Herbst Design

This version of the Herbst appliance was developed by Pancherz, in which the bands are replaced by cast splints, which fit precisely and cover the teeth in their lateral segments, fabricated from chromium-cobalt and cemented with glass ionomer cement to the teeth (252, 321). Since 1995, cast chrome-cobalt splints are routinely used. The splints cover all buccal teeth in the maxillary and mandibular arches and also the mandibular canines. In addition, the upper and lower front teeth are included in the anchorage system by way of labial arch wires that are connected to the splints.

This design of the appliance has the following advantages: the chair time is short and the appliance is strong, hygienic, and causes few clinical problems (254).

According to Hägg et al (128) both appliances produce similar effects on the dentofacial structures. However, the splinted Herbst appliances are preferable to the banded Herbst appliances because more clinical and laboratory time is required to replace fractured banded appliances.

Acrylic Splint Herbst Design

In the early 1980s, Howe (152, 153) and Howe and McNamara (154) developed 'bonded type of Herbst appliance' in the deciduous or early mixed dentition by using acrylic cap splint.

This design consists of the telescopic mechanism which is attached to acrylic splints cemented or bonded on the maxillary and mandibular dentition. For the attachment of the bite-jumping mechanism, a wire framework is used, over which 2.5-3 mm acrylic is embedded (152,153, 208).

The maxillary splint covers all the maxillary teeth except the incisors and the acrylic coverage extends from the free gingival margin of the buccal surfaces over the occlusal ending to the free gingival margin on the lingual surfaces (153). A transpalatal arch or a rapid palatal expansion screw attached to the wire framework connects the left and right parts of the splint together. Regarding the mandibular splint, the incisal one-third of the mandibular canine and incisors is covered with acrylic, which can reduce incisor proclination and the posterior teeth are fully covered (153).

The advantages of the bonded acrylic splint include attachment of the mandibular and maxillary dental arch without the use of bands, which enables use of the appliance in patients at any dental development stage, minimal tooth movement during treatment, prevention of tooth impingement and reduction of breakage incidents (152, 340).

According to Pancherz (249), the splint anchorage system has some disadvantages:

1. Tooth eruption and interocclusal adjustments during treatment are prevented. This makes it necessary to use an occlusal stabilization treatment phase after the splints are removed.

2. Unhygienic construction.

3. The bonding material is difficult to remove after treatment, especially on the approximal tooth surfaces.

The acrylic maxillary and mandibular splints can also be removable, with some differences in comparison to the bonded type. Mainly due to the fact that bonding of the acrylic splints increases the risk of decalcification, McNamara et al recommend that the Acrylic Splint Herbst Appliance should be removable in most cases (210).

Stainless Steel Crown Herbst Design

The stainless steel crown Herbst design was first introduced by Langford to avoid breakages of the bands (190). According to the author, crowns are placed on the maxillary first molars and the mandibular first premolars (or canines). The advantages of the Stainless Steel Crown Herbst Appliance include resistance to the stresses placed on the appliance, elimination of loose crowns or breakage during treatment, and avoidance of excessive protrusion of the mandibular incisors (190).

Dischinger proposed the Edgewise Bioprogressive Herbst Appliance to minimize limitations of the Herbst design and to incorporate edgewise brackets and mechanics in the correction of Class II malocclusions (91). This design includes stainless steel crowns which are attached on the maxillary first permanent molars and usually on the mandibular first premolars, while the mandibular first permanent molars are banded. No transpalatal arches are used in the maxilla so that the first permanent molars can rotate as the Class II relationship is corrected during Herbst treatment. However, according to McNamara et al (210), the incorporation of a Hyrax-type expansion screw or a transpalatal arch in the maxillary appliance adds rigidity to the appliance and minimizes the possibility of loosening. Similar stainless steel crown Herbst designs were also introduced by Smith (type II) (345, 346) and Hilgers (146).

Another stainless steel crown Herbst design is the Cantilever Herbst, which includes mandibular extension arms attached to stainless steel crowns on the mandibular first molars and mainly indicated in the mixed and early permanent dentition before the eruption of the mandibular permanent canines and first premolars (210, 345, 346). The arms extend anteriorly from the mandibular first molar lateral to the dentition and end in the premolar area. The Herbst pivots are soldered to the cantilever arms close to the buccal surface of the mandibular first premolars, and support wires are used in the shape of occlusal rests to the mandibular deciduous second molars or permanent second molars for additional stabilization.

In the opinion of Pancherz, anchorage control of the mandibular molars with the cantilevers (even when using occlusal rests on the deciduous molars) is questionable (254).

Clinical Efficacy of the Herbst Appliance

Since the reintroduction of Pancherz, a number of clinical studies have evaluated the effects of the various types of Herbst appliances. Herbst treatment affects not only the dentition but also the craniofacial skeleton, the associated soft-tissues, and the temporomandibular joint. The effects of the appliance during treatment, in the short-term posttreatment period (6-12 months after Herbst removal),and in the long-term posttreatment period (more than 6-12 months post treatment) have been well documented in the literature, regardless of the method of attachment of the Herbst mechanism to the dental arches.

Skeletal Changes

Sagittal skeletal changes

Pancherz and other investigators showed that Herbst appliance has a restraining effect on the maxillary growth, as shown by the decrease in the SNA angle during treatment (131, 133, 242, 244, 249, 260, 261). After the end of Herbst treatment, the SNA relapsed to almost pretreatment values in a short period (131, 260, 261) and decreased in the long-term posttreatment period (131, 242).

In contrast, Pancherz found a slight increase in the SNA angle during Herbst treatment and after the end of Herbst treatment (250). An additional increase was also recorded in the long-term posttreatment period (133, 250).

During treatment, the Herbst appliance exerts a posterior and upward force on the maxilla and the maxillary dentition, which can be compared to the effect of the high-pull headgear (251, 257). This headgear effect is enhanced by using the headgear-Herbst appliance, and remains stable when using the headgear-activator for retention (126). The restraining effect on the maxilla was diminished in the short (126, 260) and long-term posttreatment periods (133, 257), thus showing that maxillary growth inhibition by the Herbst appliance was of a temporary nature.

The increase in sagittal mandibular growth was evident by the increase in the SNB angle during Herbst treatment (131, 242, 244, 249, 250, 260, 261). During the short-term posttreatment period the SNB angle remained substantially unchanged (131) or slightly increased (250, 260).

In the long-term posttreatment period, the SNB angle was found to be unchanged by Hansen et al (131) whereas in some studies an increase was evident (133, 242, 250).

The increase in mandibular length produced by the Herbst appliance during treatment was also confirmed by various variables. The Co-Pg distance increased during treatment when compared the control group (108, 244); Co-Gn distance increased (57, 212) while the control group presented less increase. An increase in Ar-Pg distance was also reported (316, 319).

The Herbst appliance had a significant effect on sagittal condylar growth (276, 278), which was increased during treatment, greater than that observed in control group patients before maximum pubertal growth period (126, 259). The maximum sagittal condylar growth was observed in subjects around the maximum pubertal growth period (259) while some other investigators observed that the sagittal condylar growth was minimal (87, 108). Regarding the effective condylar growth, an upward and backward movement of Co-point were observed, which were greater than the Bolton group for both adolescents and young adults (18, 317, 320).

Furthermore, the changes in the adolescents were approximately twice those observed in the young adults (320). The change in the Co-point could be attributed to the sagittal condylar growth stimulation (259, 264), the glenoid fossa remodeling (244, 264), and the repositioning of the condyle in the fossa (264).

Vertical Skeletal Changes

According to most investigators, the Herbst appliance affected the skeletal and dental structures vertically, in both the maxilla and the mandible.

Regarding the effect of the Herbst appliance on the maxilla, it was found that the palatal plane inclination (NL/NSL) was changed during the treatment and posttreatment period, showing a rotational effect of the Herbst telescopic mechanism on the maxillary skeleton. In particular, the palatal plane tipped downwards (133, 242, 244, 250, 257).

In patients treated after the maximum pubertal growth the NL/NSL angle was decreased (133). During the short-term posttreatment period the palatal plane angle did not present significant changes, which was similar to what happened during treatment (131, 250, 257). However, a significant increase during the long-term period was observed (242, 257) which is in contrast with the decrease (133, 250) or nonsignificant changes (131) observed in other studies. On average, Pancherz and Anehus-Pancherz (257) found that the palatal plane tipped significantly downward during the whole examination period and this was about twice what was seen in the Bolton control group.

The occlusal plane (OL/NSL angle) tipped clockwise during treatment which was significantly different from the control group mainly because of the distalization and intrusion of the maxillary first molars (212, 242, 249, 250, 260, 257, 386). However, it tipped counterclockwise in the short-term posttreatment period (250, 257, 260) and further counterclockwise during the long-term posttreatment period (242, 257).

Regarding the effect of the Herbst appliance on the mandibular plane angle (ML/NSL), the majority of the investigators found an increase during treatment (131, 244, 249, 250, 260, 261, 369) while some observed a decrease (126, 133, 212) and some others found it stable (132, 244).

After Herbst removal, the mandibular plane angle decreased during the short-term posttreatment period (126, 250, 261), whereas Pancherz and Hansen (260) observed that it remained approximately unchanged. During the long-term posttreatment period the mandibular plane angle further decreased (131, 133, 250, 315) which can be attributed to the marked forward rotation of the mandible (242) or to normal growth (315). In the long-term Ruf and Pancherz found that the Herbst appliance did not have a significant effect on the ML/NSL angle and concluded that Herbst treatment does not seem to result in an undesired backward rotation of the mandible (315).

According to the findings of Valant and Sinclair, the initial opening observed after Herbst insertion was compensated for during the active treatment and settling periods. The 0.8° increase of the mandibular plane angle at the start of the treatment, due to the incisal edge-to-edge construction bite, leads to a posterior rotation of the mandible (315), while the decrease observed after Herbst removal can be attributed to the vertical effects during the late treatment and retention periods, which permitted an anterior rotation of the mandible (126), and the headgear effect, which intruded the maxillary molars (257).

The anterior lower facial height (ANS-Me) was increased during treatment (57, 244, 249, 340, 386), but according to Pancherz (249), no difference was evident between the treatment and the control groups in the 12-month posttreatment period. Further, Hagg et al (126) observed an increase of the anterior lower facial height during treatment, which remained unchanged during the retention period.

According to Nelson et al (234) the anterior lower facial height increased during treatment and the 6-month retention period.

Paulsen et al (278) and Sidhu et al (340) found that both the anterior and posterior facial heights increased during treatment. This increase resulted in a mandibular translation without causing unfavorable rotation.

Regarding changes in the mandibular morphology, the gonion angle (RL/ML) was found approximately unchanged at the end of treatment (244). Paulsen et al (278) observed that the gonion angle was increased during treatment while it was reduced by the same amount in the posttreatment period and therefore no significant differences were found comparing the pre and posttreatment changes.

Dental Changes

Sagittal Dental Changes

The Herbst appliance also affects the dental components of both maxilla and mandible. The dental changes observed in both the maxilla and the mandible can be attributed to the fact that Herbst appliance exerts a posteriorly directed force on the maxillary dentition and an anteriorly directed force on the mandibular dentition (244, 250, 259), which results in distalization of the maxillary molars, retroclination of the maxillary incisors, mesial movement of the mandibular molars, and proclination of the mandibular incisors (212, 259, 340). The latter is undesirable, especially in patients with initial incisor proclination and can be considered as anchorage loss along with the spaces between maxillary canines and first premolars (headgear effect), which are often observed after Herbst treatment (247). However, position after Herbst removal, without causing anterior crowding. According to Pancherz (247), dental changes during Herbst treatment are generally undesirable, with the exception of cases presenting anterior maxillary crowding, in which the distal movement of the posterior teeth is favorable.

Regarding the influence of the Herbst appliance on the maxillary molars, a distal molar movement and a distal tipping during treatment (212, 242, 247, 249, 250, 260). In contrast, Croft et al (87,) and Burkhardt et al (57) found a mesial movement. After Herbst removal, the maxillary first molars moved mesially during the short-term posttreatment period (126, 132, 250, 257, 260) and during the long-term posttreatment period (108, 132, 133, 250).

The mandibular first molars were moved mesially as a result of the anteriorly directed force of the Herbst appliance (57, 108, 247, 249, 259). The mandibular molars moved distally during the short-term posttreatment period (108, 126, 133, 250, 260), and further more during the long-term posttreatment period (132, 133, 250).

Regarding the effect of the Herbst appliance on the maxillary incisors, a distal movement and a retroclination were evident at the end of the treatment phase (57, 212, 242, 250, 260), which can be attributed to the pull of the transseptal fibers due to molar distalization or the altered position of the lower lip. In contrast, other investigators found no significant differences in the incisor position (244, 247, 249, 369) or a mesial movement. During the short-term posttreatment period the maxillary incisor position remained unaffected (108, 126, 250, 260). Finally, during the long-term posttreatment period the maxillary incisors relapsed by moving mesially (132, 242, 250), however, other investigators did not observe a significant change in the incisor position during the same period (133).

The mandibular incisors were also affected by the Herbst treatment, mainly because of the mesial forces exerted on the mandibular dentition, which resulted in a proclination and a mesial movement (50, 133, 242, 244, 247, 249, 250, 319). In contrast, Eberhard and Hirschfelder (97) and Hansen et al (133) found no significant influence of the Herbst appliance on mandibular incisor position. The mandibular incisor proclination observed during Herbst treatment did not have an effect on the preexisting gingival recession or did not cause gingival recession (314). Regarding the mandibular incisors' posttreatment changes, a distal movement was observed in the short-term period (108, 126, 131, 260, 261) thus returning approximately to their initial position (260, 261). Furthermore, the mandibular incisor proclination was reduced during the first year of the posttreatment period (126, 131, 250, 261). During the long-term posttreatment period the mandibular incisors moved distally (131, 132, 133, 242, 250), while a retroclination in relation to the sella-nasion line was evident (131, 242), which can be attributed to the mandibular growth rotational changes.

Vertical Dental Changes

Regarding maxillary dental changes, it was observed that the maxillary first molars were intruded during the treatment period (126, 212, 249, 257, 334). In contrast, an extrusion was evident in other studies (57, 334). They were extruded during the short-term posttreatment period and the long-term follow-up (126, 257).

Pancherz and Anehus-Pancherz (257) found that after a 7-year observation period, including the treatment and the short- and long-term posttreatment periods, the maxillary first molars were extruded by 3.9 mm. The maxillary second premolars also extruded during treatment (249).

Regarding the maxillary incisors, an extrusion was observed at the end of treatment (57, 126) while no significant changes were found during the retention period (126).

With regard to the mandibular dental changes, the incisors were intruded, which can be attributed to the proclination of these teeth, and the molars extruded (125, 212, 249, 334, 340). However, Burkhardt et al (57) observed an incisor extrusion. During the 6-month retention period, the mandibular molars and incisors extruded equally (126). Regarding the mandibular first premolars, an intrusion was found at the end of the treatment, due to the fact that these teeth served as anchors to the appliance (97). Finally, the mandibular second premolars were extruded after treatment (249). Konik et al (182) found that proclination of the lower incisors (anchorage loss) in late treated (after pubertal growth) subjects is larger than in early treated subjects.

The overjet correction was achieved as a result of the dental and skeletal changes produced by the Herbst treatment. In particular, a reduction was evident at the end of the treatment (133, 242, 244, 247, 249, 250, 259, 340). This reduction was even more pronounced when the headgear Herbst and a step-by-step mandibular advancement were used (126). After Herbst removal, the overjet relapsed during the short-term posttreatment period (126, 250, 260, 261), which can be attributed to the relapse in the mandibular incisor inclination or to recovery of the upper and lower teeth movements. In contrast, Franchi et al (108) found that the overjet remained almost

unaffected. On a long-term posttreatment basis, a relapse in the overjet was observed (132, 133, 242, 250). In total, the Herbst appliance caused an overjet correction between 3.3 and 5.7 mm from the pretreatment to the long-term posttreatment period (130, 132, 133, 242, 250).

The incisal edge-to-edge relationship leaves the buccal segment out of occlusion, which contributes to the allowance of normal vertical tooth eruption and growth in the posterior segments (244, 247). Thus, a reduction in the overbite should be anticipated. After Herbst treatment the overbite was reduced (57, 244, 249, 250, 334, 340). A relapse during the short-term posttreatment period was evident, mainly because of the relapse in the inclination of the mandibular incisors (133, 249). In addition, an increase was observed during long-term follow-up (130, 132, 250). The total overbite reduction during the total observation period was between 1.0 and 2.6 mm (130, 250).

In 2009, Martin and Pancherz (204) analyzed the effect of the cast Herbst/multibracket (MB) appliance on the position of the mandibular incisors in relation to the amount of mandibular advancement at the beginning of treatment. They screened 133 patients with Class II Division 1 malocclusions. The subjects were divided into 3 bite-jumping groups: I, 49 subjects with bite jumping of <7 mm; II, 44 subjects with bite jumping of 7.5 to 9.5 mm; and III, 40 subjects with bite jumping of >9.5 mm. Only group I with small (S) and group III with large (L) bite jumping were considered. The average ages of the subjects in the 2 bite-jumping groups were 13.6 ± 2.4 years in the S group and 14.7 ± 4.7 years in the L group. The average treatment time with the Herbst/MB appliance was 19 months. Lateral headfilms were evaluated at 3 times: before Herbst treatment, after Herbst treatment, and after MB treatment. Results: During the Herbst phase, the mandibular incisors were significantly intruded, protruded, and proclined in both bite-jumping groups. Larger tooth movements occurred in group L than in group S. During the MB phase, comparable relapsing incisor tooth movements were seen in the 2 bite-jumping groups. There was moderate correlation between bite-jumping and incisor position changes during the Herbst and the Herbst/MB treatment periods. No associations were found between the amount of bite jumping and the changes of sagittal and

vertical jaw relationships, age, and treatment growth period. In conclusion, during the Herbst treatment period, there was an association between bite jumping and movement of the mandibular incisors: the greater the bite jumping, the larger the intrusion, protrusion, and proclination of teeth. During the MB treatment period, relapsing incisor tooth movements occurred that were independent of the original amount of bite jumping.

Transverse Changes

Maxillary arch length, intercanine width, and intermolar width were increased significantly, while the mandibular arch displayed minimal change (369).

Hansen et al (130) found an increase of the upper and lower arch perimeters after Herbst treatment, which relapsed during the short-term observation period. They observed the same effects in the mandibular intercanine arch width and the upper intermolar width, while the lower intermolar width appeared to be unaffected by treatment. In the long-term observation period, the arch perimeters showed a normal dental developmental pattern.

Soft-tissue Changes

The soft-tissue profile was improved at the end of Herbst treatment (244, 258). The upper lip was retruded during treatment (57, 258) while the lower lip remained unchanged (257) or retruded less than the upper lip (57). During the short-term posttreatment period the upper and lower lips retruded nonsignificantly, while in the same period the facial profile showed a relapse. Regarding the long-term posttreatment effects on the soft-tissues, a retrusion of the upper and lower lip was observed (258).

Schweitzer and Pancherz (334) reported that, Herbst treatment in Class II Division 2 patients resulted in a reduction of the lower lip overlap on the maxillary incisors by 1.8 mm, which remained stable during the 12-month posttreatment period.

Effects on Temporomandibular Joint

The placement of the Herbst appliance caused and anterior and downward movement of the condyle which induced adaptive growth, modeling and remodeling of the condyle, the glenoid fossa, and articular tubercle (244, 276, 278). Condylar adaptive growth, modeling and remodeling were observed at the posterior-superior border of the condyle, and glenoid fossa remodeling at the anterior surface of the postglenoid spine (320), while it was also observed that fossa remodeling followed that of the condyle and both contributed to the mandibular forward growth (278, 317, 320). The newly formed bone remained unchanged after Herbst treatment in adult patients, where normal growth had ceased (276).

The mechanism of the condylar and glenoid fossa modifications was proposed by Voudouris and Kuftinec (376) and tested by Voudouris et al (377). The growth relativity hypothesis involved mandibular displacement, viscoelastic tissue extension forces to the condyle through several different attachments and transduction of forces radiating beneath the fibrocartilage of the glenoid fossa and condyle, which resulted in redirected and enhanced condylar-glenoid fossa growth, mainly due to significant bone modeling. Thus, significant bone formation was observed in the glenoid fossa which showed a downward and forward direction.

The articular disk, which retruded at the start of the treatment as an adaptive response to the incisal edge-to-edge position, returned to approximately its initial position after appliance removal, and a slightly retruded position remained in only a few patients (265). Further, the TMJ was not affected during Herbst treatment (244, 249, 318), as the condyles returned to their normal fossa position after removal of the appliance (260), mainly due to the increase of the sagittal condylar growth, and the remodeling of the glenoid fossa (244, 317). For these reasons, the condyle-fossa relationship was unaffected at the end of the therapy (290, 317).

In 2003, Popovich et al (290) performed a systematic review to evaluate the effect of the Herbst appliance on TMJ morphology and they concluded that: (1) Changes in condyle position relative to the glenoid fossa are minor and not clinically

significant. (2) The nature of condylar and glenoid fossa remodeling has not been established. (3) Disc position change has not been established.

Some undesirable functional disturbances were observed during Herbst treatment, such as TMJ sounds (134), masticatory muscle tenderness (134, 249), and TMJ tenderness on palpation, which can be attributed to the lack of occlusal buffer during the first months of treatment (249, 256). According to Ruf and Pancherz (321), bite jumping with the Herbst appliance did not cause muscular temporomandibular disorders (TMD), decreased the prevalence of capsulitis and structural condylar bone changes, and did not cause disk displacement in patients with normal pretreatment disk position. Furthermore, the frequency of condylar displacement, TMJ sound findings or TMDs in patients treated with the Herbst appliance was not significantly greater than that of normal population, both for the short-term and long-term periods (318).

Thus, Herbst treatment did not seem to have any adverse effects on the TMJ function or cause TMDs or unfavorable structural changes on a short or long-term basis (134, 249, 318, 321). Also, TMJ sounds, muscle tenderness, and symptoms which were observed before the initiation of treatment were resolved mainly due to the normal occlusal conditions established, and possibly because of the repositioning of the displaced disk caused by the jumped position of the condyle during treatment (244, 249).

In 2004, Pancherz and Michailidou (263) assessed the amount and direction of glenoid fossa displacement, condylar growth, and "effective" temporomandibular joint (TMJ) changes in 3 vertical facial-type groups of Class II Division 1 malocclusions treated with the Herbst appliance in a long-term study. A comparison was made between 38 normodivergent, 17 hypodivergent, and 13 hyperdivergent subjects. Lateral headfilms from before, after, and 5 years after treatment were scrutinized. Glenoid fossa displacement, condylar growth, and "effective" TMJ changes were analyzed. Treatment changes: in all facial-type groups, the glenoid fossa was displaced anteriorly and inferiorly. No differences existed between the 3 groups. Condylar growth and "effective" TMJ changes were directed posteriorly and superiorly. The changes in posterior direction were more apparent in the

hyperdivergent group than in the normodivergent and hypodivergent groups. Posttreatment changes: in all facial-type groups, the fossa was displaced posteriorly. No differences existed between the 3 groups. Condylar growth and "effective" TMJ changes were directed more vertically compared with the treatment changes. The changes in posterior direction were more pronounced in the hyperdivergent group than in the other 2 groups. It was found that the amount and direction of TMJ growth changes (fossa displacement, condylar growth, and "effective" TMJ changes) were only temporarily affected favorably in the sagittal direction by Herbst treatment. Condylar growth and "effective" TMJ changes were directed more posteriorly in hyperdivergent than in hypodivergent Herbst subjects. This was true for both treatment and posttreatment period changes.

In 2008, Serbesis-Tsarudis and Pancherz evaluated the ''effective'' TMJ changes (the sum of condylar modeling, glenoid fossa modeling, and condylar position changes within the fossa), and their influence on chin position in patients with a Class II Division 1 malocclusion treated orthodontically with a multibracket appliance and Class II elastics (Tip-Edge) and orthopedically Herbst. They concluded that jumping the bite with the Herbst appliance has a favorable sagittal orthopedic effect on the mandible on a short-time, but not on a long-time basis (336).

In 2009 Aidar et al (2) evaluated the changes in the position and morphology of the disc in the temporomandibular joint (TMJ) with magnetic resonance imaging (MRI). The subjects were 32 consecutive adolescent patients with Class II Division 1 malocclusion treated with the Herbst appliance. The MRIs were obtained immediately before treatment (T1), 8 to 10 weeks after appliance placement (T2), and 12 months later (T3). Qualitative evaluation of the MRIs showed that, in 42 (65.62%) of the 64 TMJs, the disc was positioned within normal limits at T1. Because of the advancements caused by the Herbst appliance, a tendency for disc retrusion was observed at T2, but at T3 the disc had returned to normal limits. In 22 TMJs (34.37%), the disc was displaced at T1, and no changes were observed at T3. In most subjects, comparison of the morphology of the disc at T1, T2, and, T3 showed no significant change. They concluded that Herbst therapy does not cause adverse effects on the morphology and position of the articular disc in the short term.

Effects on Muscles

Regarding the effects of the Herbst appliance on the masticatory muscles, the incisal edge-to-edge relationship caused a noticeable reduction in the electromyographic (EMG) activity of both the masseter and temporal muscles during maximal biting in an intercuspal position, which recovered noticeably almost to pretreatment values 3-6 months after placement of the Herbst appliance (193, 255). Regarding the lateral pterygoid muscle activity, an increase in the EMG pattern was observed after wearing the appliance which was reduced markedly in a 6-month period (148), which led to the conclusion that muscular adaptation takes place soon after Herbst placement, and before the appearance of morphologic changes due to functional treatment (148).

When the Herbst appliance was removed, the EMG activity of the masseter and temporal muscles was found to be increased in comparison to pretreatment values (255). Twelve months posttreatment , when the occlusion was stabilized, the contraction pattern in the two muscles was similar to that observed in subjects with normal occlusion (249).

In a study of Herbst treatment effect in a hypodivergent patient in late adolescence, Bakke and Paulsen (17) found a reduction of the powerful masseter muscle strength by about 40% and an increase of the minimal pterygoideus muscle strength after achievement of a normodivergent jaw relation with a more equal strength of these muscles, in accordance with findings by Moeller (219).

Considering the latest studies about Herbst therapy, in 2006, Van Laecken et al (370) investigated skeletal and dental changes in patients with Class II malocclusions treated with the edgewise Herbst appliance. Fifty-two consecutive patients were treated with the edgewise Herbst appliance; 32 (18 girls, 14 boys) met the criterion of 16 months out of Herbst treatment and were included in the study. Mean treatment time with this appliance was 8.0 _ 1.8 months. Cephalometric measurements were taken at pretreatment, posttreatment, and 16 months after removal of the Herbst appliance, and the results were compared with 32 untreated Class II subjects from the Bolton Brush Study, matched for sex, age, and cephalometric dentofacial

morphology. After 8 months of Herbst treatment, incisal relationship was overcorrected to an end-to-end incisal relationship and improved 8.4 mm, compared with the control group. The maxilla moved backward 1.4 mm at Point A, and the mandible moved forward 1.7 mm. The maxillary incisors moved lingually 1.7 mm, and the mandibular incisors were proclined 3.6 mm. The molars were corrected to a Class III relationship with a change of 7.2 mm compared with the control group. The mandible moved downward and forward. However, the condyle showed only 0.2 mm forward movement in the fossa. Sixteen months after appliance removal, the molars had relapsed into a Class I relationship, for a net change of 2.4 mm compared with the control group. Net overjet gain was 2.7 mm. Net restraint of maxillary growth was 1.3 mm, and net forward movement of the mandible was 1.0 mm. The maxillary incisors had no net movement, and the mandibular incisors had a net forward movement of 0.3 mm. Overall, skeletal change contributed 85% of the net overjet correction. They concluded that Class II treatment with the edgewise Herbst appliance is accompanied by both skeletal and dental changes. The changes were stable, with significant skeletal differences remaining 16 months after appliance removal. The forward and downward movement of the mandible with minimal changes in the position of the condyles in the fossa suggests a combination of condylar growth and remodeling of the glenoid fossa with treatment.

Flores-Mir et al (103) evaluated skeletal and dental changes in growing individuals through lateral cephalograms obtained after the sole use of the splint-type Herbst appliances in Class II Division 1 malocclusions in a systematic review. The selected studies all showed statistically significant changes in the anteroposterior length of the mandible, vertical height of the ramus, lower facial height, mandibular incisor proclination, mesial movement of the lower molars, and distal movement of the upper molars. Posttreatment relapse in overjet and molar relationship was also observed. In another systematic review, in 2009, Barnett et al (19) evaluated the relative skeletal and dental changes produced by the crown- or banded- type Herbst appliance in growing Class II Division 1 malocclusion cases. Proclination and anterior movement of the lower incisors, overjet reduction, and improvement of first molar relationship thorough mesial movement of the first molars, reduction of ANB angle, and an increase in the mandibular plane angle were reported. There were

mixed findings as to mandibular sagittal length and position and increases in lower face height, both anteriorly and posteriorly. No statistically significant changes were noted in the sagittal length or position of the skeletal maxilla. They concluded that dental changes have more impact than skeletal changes in the correction of Class II Division 1 malocclusions with the crown or banded Herbst appliance.

In 2009 Baccetti et al (14) compared the effects of 2 protocols for single-phase comprehensive treatment of Class II Division 1 malocclusion (bonded Herbst followed by fixed appliances vs. headgear followed by fixed appliances and Class II elastics) at the pubertal growth spurt. Results showed that the Herbst group had a significant increase in mandibular protrusion. The increase in effective mandibular length (Co-Gn) was significantly greater in both treatment groups when compared with natural growth changes in the Class II controls. Significantly greater improvement in sagittal maxillomandibular relationships was found in the Herbst group. Retrusion of maxillary incisors and mesial movement of mandibular molars were significant in the headgear group. The Herbst group showed significantly greater forward movements of soft-tissue B-point and pogonion compared with both the headgear and the control groups. In conclusion, they pointed out that Class II treatment with either protocol during the pubertal growth spurt induced significant favorable dentoskeletal and occlusal changes. Herbst appliance had a greater favorable impact on the advancement of the chin. The clinical indications for the preferential use of the Herbst appliance at puberty are a small mandibular angle and mandibular retrusion before treatment. When treated with the Herbst protocol, those Class II patients had the greatest probability of achieving significant improvement in the profile by advancement of the soft-tissues of the chin.

Moro et al (220) evaluated the skeletal, dentoalveolar, and soft-tissue changes that occur during Class II correction with the Cantilever Bite Jumper (CBJ) in a prospective cephalometric study. The study conducted on 26 subjects with Class II Division 1 malocclusion treated with the CBJ appliance. A comparison was made with 26 untreated subjects with Class II malocclusion. Lateral head films from before and after CBJ therapy were analyzed. Class II correction was accomplished by means of 2.9 mm apical base change, 1.5 mm distal movement of the maxillary molars, and

1.1 mm mesial movement of the mandibular molars. The CBJ exhibited good control of the vertical dimension. The main side effect of the CBJ was that the vertical force vectors of the telescope act as lever arms and can produce mesial tipping of the mandibular molars.

4.5.2.1.2.4.2. Jasper Jumper

One of the disadvantages of the Herbst appliance is the rigidity of the Herbst bite jumping mechanism itself. Although every attempt is made to allow freedom of movement by enlarging the attachment holes of the tube and plunger to the axles, the bite jumping mechanism restricts movements of mandible (168).

In an attempt to overcome these problems, in 1987 Jasper (167) developed a new pushing device known as the Jasper Jumper™ (American Orthodontics, Sheboygan, Wis). This is a flexible intraoral force module, which may be seen as a modification of the Herbst appliance (168).

The system is composed of two parts, the force module and the anchor units.

Force module: The force module, analogous to the tube and plunger parts of the Herbst bite jumping mechanism, is flexible. The force module is constructed of a stainless steel coil or spring that is attached at both ends to stainless steel endcaps, in which holes have been drilled in the flanges to accommodate the anchoring unit. This module is surrounded by opaque polyurethane covering for hygiene and comfort. The modules are available in seven lengths, ranging from 26 mm to 38 mm in 2 mm increments. They are designed for use on either side of the dental arch. When the force module is straight, it remains passive. As the teeth come into occlusion, the spring of the force module is curved axially as the muscles of mastication elevate the mandible, producing a range of forces from 1 to 16 ounces. This kinetic energy then is captured when the force module is curved, and the force is converted to potential energy to be used for a variety of clinical effects.

To determine the correct length of the module, the distance between the mesial of the upper molar tube and the point of insertion to the mandibular arch is measured.

Adding 12 mm to this measurement will give the appropriate length of the jumper (168).

Anchor units: A number of methods are available to anchor the force modules to both the permanent and mixed dentitions (168).

Attachment to the main arch wire. The most common method of attachment of the force module to the dental arches in patients in the permanent dentition is through the use of previously placed fixed orthodontic appliances. When the jumper mechanism is used to correct a Class II malocclusion, the force module is attached posteriorly to the maxillary arch by a ball pin that is placed through the distal attachment of the force module and then extends anteriorly through the face-bow tube on the upper first molar band. The ball pin is anchored in position by having the clinician place a return bend in the ball pin at its mesial end.

Anteriorly, the module is anchored to the lower arch wire. Bayonet bends are placed distal to the mandibular canines and small Lexan beads are slipped over the arch wire to provide an anterior stop. The mandibular arch wire is threaded through the hole in the anterior endcap and then ligated in place. The removal of the brackets on the lower second premolars in addition to the lower first premolars (as advocated originally) allows the patient greater freedom of movement.

The disadvantages of this method are (43): (1) Jaw opening is limited because the lower portion of the jumper tends to bind at the second bicuspid. (2) Replacement of a broken jumper requires removal of the entire archwire. (3) If an arch breaks or comes untied at the distal tieback, all the force is transferred to the anterior teeth, which tends to tip them forward, depress them, and open space. (4) Removing the jumper for an occlusal check is time-consuming. (5) In an extraction case, it is difficult to close spaces because the jumper must be attached to the arch before closing loops are bent.

Attachment to auxiliary arch wires. An alternative design incorporates the use of "outriggers " (43). This 0.016 x 0.022-inch (0.018-inch slot) or 0.018 x 0.025-inch (0.022-inch slot) auxiliary sectional wire allows the clinician to leave the premolar bonds or bands in place by attaching the force module to a sectional wire that is

anchored anteriorly to the main archwire between the first premolar and canine. In addition, because freedom for the modules to slide is increased, there is a greater range of jaw movement. Repairs and replacement of the jumper components are simplified with this outrigger modification.

The segmental arch wire is attached posteriorly through an auxiliary tube located on the lower first molar band. The auxiliary wire can be bent so that the vestibular section is parallel to the occlusal plane, or a shorter vertical step can be placed posteriorly so that the inclination of the outrigger more closely approximates the downward and forward growth direction of the patient's face. The posterior part of the jumper module is attached to the ball pin placed through the maxillary molar tube, as described previously.

If outriggers are used to anchor the module to the mandibular dentition, care must be taken to assure that the sectional arch wire provides adequate space between the alveolus and the gingiva to allow the module to slide without tissue impingement. Contouring the sectional arch wire and placing first-order step-out bends in the arch wire may be helpful. Once the module has been placed, the module should slide smoothly along the sectional outrigger wire.

Advantages of this method are (43): (1) The sectional arches can be bent by assistants during free moments. After the clinician measures, the jumper can be attached by an assistant. (2) If breakage occurs, there is no adverse effect on the dentition. (3) The material is inexpensive. (4) It is easy to change or remove jumpers. (5) The appliance delivers force distal to the mandibular molar tube, rather than to the arch wire. (6) Full jaw opening is possible. (7) A longer jumper van be used, allowing more freedom of movement and reducing the chances of breakage. (8) The mandibular first bicuspid brackets do not need to be removed to prevent over eruption. (9) A fatigued jumper can be reactivated by placing a Rocky Mountain Lock mesial to the Teflon friction ball, positioning the ball more distally.

Attachment in the mixed dentition. The force module also can be used in patients with mixed dentitions whose premolars have not yet erupted. The maxillary attachment is similar to that previously described. The mandibular attachment of the

force module is through an arch wire that extends from the brackets on the lower incisors posteriorly to the first permanent molars, bypassing the region of the deciduous canines and molars. The use of a transpalatal arch and fixed lower lingual arch is mandatory so as to control potential unfavorable side effects produced by the appliance (e.g., molar and incisor tipping and flaring).

Anchorage

Before insertion of the jumpers, the arches should be aligned and leveled. Full sized upper and lower arch wires should be inserted, preferably including the second molars if erupted, and cinched back to enhance anchorage. As with the Herbst appliance, mesial movement of the lower incisors has been reported with this appliance system (168, 229). Unfavorable dentoalveolar adaptations can be minimized in the mandible through proper anchorage preparation. Anterior lingual crown torque can be placed in the arch wire. Alternatively, lower incisor brackets with 5° of lingual crown torque incorporated into the slot of the bracket also can be used to prepare anchorage. Lingually torqued lower incisor brackets are used in addition to, not as a substitute for, anchorage in the mandible. The use of a fixed lower lingual arch is encouraged strongly in most instances. This type of anchorage preparation is used routinely except when significant lower incisor proclination is desired as part of the overall treatment plan (168). A transpalatal arch can be used in those instances in which distal maxillary molar movement is to be minimized and mandibular adaptations are to be maximized. A transpalatal arch is not incorporated into the appliance system if maxillary dentoalveolar movement is desired (168).

The jasper jumper is normally worn for a period of six to eight months. Since the occlusion is often established after only four months; the clinician tends to remove the appliance too early. However, the patient should be persuaded to wear the appliance longer in the interest of increased stability of the results. If the spring survives the long treatment time of eight months Jasper can be activated (335).

Treatment Effects

Blackwood (43) stated that when the Jumper is first installed, it bows toward the cheek. Over time, the mandible moves forward to a neutral position. Mastication then

helps deliver intrusive and distalizing forces on the upper molars, much as a high-pull facebow would, along with intrusive forces that work to level the lower anterior teeth. Furthermore, the forward and downward positioning of the mandible is along the y-axis, allowing the jaws freedom for normal growth. The usual results of using the Jasper Jumper are:

- Intrusion and distalization of the upper molars, with occasional opening of the posterior bite similar to that seen with a Herbst appliance.
- Some indication of condylar growth.
- Anterior migration of the mandibular teeth through alveolar bone.
- Intrusion of the lower incisors.
- Expansion of the upper molars if heavy constricted maxillary archwires and/or transpalatal bars are not used.

One of the treatment effects produced most easily by the force modules is the distalization of the upper posterior segment (i.e., the headgear effect). This type of movement is achieved by not cinching or tying back the maxillary arch wire but rather by allowing the arch wire to remain straight and slightly extended past the buccal tubes. Light forces (i.e., 2 to 4 ounces) then can be expressed by the modules to distalize the upper molars. Because the forces are resisted by the entire lower dentition, minimal changes in mandibular dentition are noted. The headgear effect can be produced not only in actively growing patients, but also in some adult patients in whom maxillary molar distalization is desired. 22 There is no evidence to support the hypothesis that this type of appliance can be used to promote mandibular growth in adult patients (168).

Cope et al (82) performed the first quantitative guideline in order to describe orthopedic and orthodontic changes associated with Jasper Jumper therapy. A sample of 31 consecutively treated Cl II patients was compared with an untreated sample based on age, sex and mandibular plane angle. The results showed that the majority of Class II correction was due to dental, rather than skeletal change. The maxilla underwent significant posterior displacement. While the mandible showed little or no growth stimulation or downward/forward glenoid fossa remodeling, it did rotate clockwise slightly. The maxillary molars underwent posterior tipping and relative

intrusion. The maxillary incisors retroclined and extruded. Clockwise or backwards rotation was evident for the mandible. The mandibular molars translated and tipped mesially and erupted while the mandibular incisors proclined and intruded. The same treatment effects were reported by later studies (83, 185, 229, 351, 379). Covell et al (83) added that molar tipping and maxillary incisor retroclination were corrected, although the mandibular incisors remained proclined during orthodontic finishing.

Weiland and Bantleon (379) studied the effect of the Jasper Jumper appliance on the dentofacial complex in 17 consecutive growing patients who had Class II, Division 1 malocclusions. They found that the correction of the Class II malocclusion was a result of skeletal (40%) and dental (60%) changes.

Nalbantgil et al (229) evaluated the skeletal, dental, and soft-tissue changes in late adolescent patients treated with Jasper Jumpers applied with sectional arches. The study sample consisted of 30 subjects (15 treated, 15 untreated) with skeletal and dental Class II malocclusion. The results showed that Class II correction was achieved mostly through dentoalveolar changes and skeletal changes played a minor role. The results revealed that the appliance had a limited skeletal effect on the maxilla. This restraint of forward maxillary growth was the only skeletal change caused by the appliance. This finding is in accordance with the results of other investigators who showed that the appliance had a high-pull headgear effect on the maxilla (82, 83, 168, 218, 335).

Küçükkeleş et al (185) compared 25 growing patients with 20 control subjects of similar skeletal developmental age. The study showed similar results with the previous studies. Jasper Jumper effectively corrected Class II malocclusion, but the changes were 80% dentoalveolar.

Stucki and Ingervall (351) showed that seven months after removing the force modules, approximately 60% of the overjet reduction and 75% of the molar correction remained. This seems comparable to posttreatment development using the Herbst appliance (250). In Herbst therapy, it is advised to overcorrect occlusal relationships to an end-to-end incisor position. In the following 6 months, the occlusion settles (132). In the long term, relapse seems to be clearly related to

unstable occlusion, as is usually seen in mixed dentition cases. Therefore, it is recommended to retain the achieved occlusal relationships for at least 2 years with an activator (133). As it is very difficult to overcorrect occlusal relationships with a flexible module, it is advisable to retain the achieved sagittal occlusal relationships with light Class II elastics during ongoing fixed appliance therapy after removing the Jasper Jumpers (272).

4.5.2.1.2.4.3. Mandibular Protraction Appliance (MPA)

Coelho Filho published an article in 1995 in which he presented the mandibular protraction appliance (MPA), a fixed dentofacial orthopedic noncompliant device (74). Although he considered his treatment results with the MPA satisfactory, he reported frequent breakage of the appliances. This led him to introduce several modifications (75, 76) until the appliance reached its fourth version (77), which was more resistant to breakage and much more stable during functioning than the previous ones. MPA IV functions much like a Herbst appliance but uses smaller tubes and rods and these attach to the maxillary first molar headgear tube and the mandibular edgewise archwire. The maxillary extremity of the appliance ran around a 1 mm sectional stainless steel wire that was bent 90° before entering the distal side of the 0,045'' round molar tube and was locked in its mesial side.

Before installation, the MPA IV must have its length adequately defined so as to keep upper and lower incisors in an edge-to-edge relationship when the patient closes the mouth. This measurement corresponds to the distance from distal of the upper first molar tube to the circular loop placed in the archwire distal to the lower cuspid and is taken in the incisor edge-to-edge position with midlines coincident. Upon installation of the MPA, a posterior open bite appears and causes discomfort to the patient. The patient must be informed that this open bite gradually closes by itself with time and within about 1,5 weeks (270).

When the MPA is activated, the mandible is brought forward initially and later reverses by the action of the retracting musculature, concomitantly retracting the maxillary dentoalveolar complex. During this process, intrusion of the upper occlusal

plane often occurs, permitting mandibular counterclockwise rotation and mandibular anterior translation (270).

The MPA fulfills its function in periods of 6-8 months for growing patients and up to 1 year for adults, although this time difference is not always deemed necessary (270).

The MPA has proved its efficacy in the treatment of: late mixed dentition malocclusions, growing patients in the pubertal period, upper molar distalization, asymmetric cases (Class II Division 1 or 2), adult patients, first molar extraction cases (270).

Applying MPA in the mixed dentition may cause too much labial inclination of the lower incisors. One alternative to diminish such risk could be the gradual activation of the appliance.

Growing patients' responses to MPA treatment are usually positive, often demonstrating great increments of mandibular growth, with an apparent restriction in growth of the maxilla (75). This is often associated with widening of the maxillary dental arch. In spite of expansive vector, they do not combine the MPA with palatal bars, considering the frequent observation of the aperture of the heavy stainless steel 0,019× 0,025'' archwire to be enough.

If upper molars are free to slide along the archwire when pushed by the MPA, their individual movement obtained by this means is normally very large.

Class II Division 1 or 2 cases associated with midline shifts respond well to MPA treatment through its unilateral or bilateral use with greater activation on the discrepancy side (78). The correction may occur by distal movement of the upper first and second molars on the Class II side and then lateral movement of the other teeth to the space created by the MPA.

Since the alterations induced by the MPA are apparently dentoalveolar in nature, there is no conventional limit to treatment based on age if the teeth and their support are healthy (79). For adults, the length of time for which the MPA must stay in the mouth does not differ much from the time applied to growing patients: around 6-8

months. Adult patients have demonstrated much better stability than younger patients.

In first molar extraction cases an MPA is used to anchor the upper second molars while maxillary anterior teeth are retracted.

The MPA is not indicated or use in the deciduous and early mixed dentition. This is due to the lack of adequate dental support to resist the heavy muscular force derived from the activation of the appliance. Cases with excessive labial inclination of lower incisors are also contraindicated if such inclination cannot be corrected before MPA installation (270).

The main advantages of the MPA includes several features such as reduced cost, ease of construction and installation, acceptance by the patient, lightness, reduced failure occurrence and, most of all, the predictability of its results (270).

In 2007 Siqueira et al (343) compared changes in the dentoskeletal and soft-tissues after orthodontic treatment of Class II Division 1 malocclusions between the cervical headgear and the mandibular protraction appliance. The sample consisted of 50 patients divided into 2 groups of 25 patients each. Group 1 patients were treated with CHG and fixed appliance, and group 2 patients were treated with the MPA and fixed appliances. The CHG group showed statistically greater restriction of the anterior displacement of the maxilla, improvement of the skeletal Class II relationship, decreased facial convexity, extrusion and distalization of the maxillary first molar, and extrusion of the mandibular incisors while the MPA group had statistically greater increases in maxillary length, mandibular protrusion, maxillary incisor retrusion, mesial displacement of the mandibular first molars, and protrusion of the lower lip.

4.5.2.1.2.4.4. Eureka Spring

The Eureka Spring was first described in 1997 by DeVincenzo (88). The device includes triple telescoping action, flexible ball-and-socket attachments, a completely encased spring that remains intact even if the device becomes disengaged, and a shaft

for guiding the spring. The main component of the Eureka Spring is an open-wound coil spring encased in a plunger assembly. The ram is made from a special work-hardened stainless steel that has been precision-machined. At the attachment end, the ram has either a closed or an open ring clamp that attaches directly to the archwire. The plunger has a tolerance of 0.002'' within the cylinder. A triple telescopic action permits the mouth to open as wide as 60 mm before the plunger becomes disengaged. If this occurs, the system can easily be reassembled by the patient. The cylinder assembly is connected to a molar tube with a 0.032'' wire that has been annealed at the anterior end. A 0.036'' solid ball at the posterior end acts as a universal joint, permitting lateral and vertical movements of the cylinder.

Several attachments to the mandible archwire are available: The *Classic closed ring*, the most popular model, requires archwire removal for insertion and removal, whereas the *Classic open ring* permits attachment without archwire removal. The *Quick connect model* utilizes a block attached to the archwire from which a neck and sphere protrude (273).

Light (150g) and heavy (225g) spring force modules, depending on the configuration of the internal spring, are available. In adult patients requiring significant Class II corrections, the heavy spring module should be considered. In very young patients the light force module is preferred. In mid- to late-adolescent patients, both modules are used. If there is a bilateral Class Gilmore severe on one side, the heavy force spring module may be placed on that side while the light force module can be used contralaterally. The heavy force module will correct sagittal discrepancies more rapidly and will also produce more maxillary posterior dental intrusion (50).

Frequent appointments permit the clinician to make archwire adjustment bends with the goal that within 3-5 months of cessation of Eureka Spring therapy, active treatment should be completed (273).

According to DeVincenzo Eureka Spring has following advantages (88):

- It permits unlimited mandibular movements
- It can be used in Class II and Class III malocclusions

- It can be used in conjunction with extra oral force
- It is less prone to breakage
- Spring come in two sizes and are converted at time of insertion into left and right action; therefore inventory is minimal
- Interarch force magnitude in the range of 50 to 150 grams, which can be easily altered and accurately assessed.
- No auxiliary attachments are required.

Stromeyer et al (350) investigated the effect of the Eureka Spring appliance on 37 consecutively treated, noncompliant patients with bilateral Class II malocclusions. Lateral cephalograms were taken at the start of orthodontic treatment (T1), at insertion of the ES (T2), and at removal of the ES (T3). The average treatment interval between T2 and T3 was four months. The Class II correction occurred almost entirely by dentoalveolar movement and was almost equally distributed between the maxillary and mandibular dentitions. The rate of molar correction was 0.7 mm/mo. Likewise, for every 3mm of sagittal correction 1 mm of maxillary molar and mandibular incisor intrusion was measured. There was no change in anterior face height, mandibular plane angle, palatal plane angle, or gonial angle with treatment. There was a 2° change in the occlusal plane resulting from intrusion of the maxillary molar and the mandibular incisor. Only 10% of the overjet correction was achieved by skeletal changes, and 90% occurred by dental compensation. Based on the results in this sample, the ES appliance was very effective in correcting Class II malocclusions in noncompliant patients without increasing the vertical dimension.

DeVincenzo and Smith (89) evaluated more than 100 patients utilizing Eureka Spring therapy. The results showed that about 25% experienced subsequent relapse of at least 2 mm. The direction of the relapse closely mimicked the direction of previous correction. That is, if in a particular patient most of the correction occurred by maxillary tooth distalization, most of the subsequent relapse also occurred there. If correction was equally distributed in both arches, so was the subsequent relapse.

4.5.2.1.2.4.5. Twin Force Bite Corrector

The Twin Force Bite Corrector (TFBC) (310) was developed from a combination of concepts from the Herbst and Jasper Jumper. The appliance incorporates the Herbst concept by having a constant anterior protrusion of the mandible by means of a plunger system with a fixed distance. Additionally, an active push coil delivers a constant force of approximately.

The TFBC is a bilateral interarch push-type appliance that is individually tied to the archwires on each side. Each element is made up of two 16 mm telescopic cylinders parallel to each other. Within each cylinder and in opposite ends, a plunger is incorporated. An active nickel titanium coil within the cylinder pushes each plunger outside the cylinder a distance of 15 mm. At the free end of each plunger, a double-sided housing attachment is secured with a titanium hex bolt to the archwire. The attachment is a free movable ball joint that allows easy intraoral attachment from a coronal or gingival direction. When the plungers are fully compressed within the cylinders, the appliance measures 29 mm from one attachment to the other. A short version of the appliance that measures 27 mm is also available. This version is indicated in patients with congenitally missing premolars or in patients who underwent extraction of these teeth and a Class II malocclusion still persists.

The TFBC is attached mesial to the first maxillary molar and distal to the lower canine. When it is fully compressed, the patient should have the mandible protruded to an edge-to-edge incisor relationship. The push coil within the plunger adds an oscillating force with normal masticatory function. The force of this coil when fully compressed is 210 g.

The appliance should be delivered with stiff upper and lower archwires. Additionally, due to the expected flaring effect of the lower incisors, a 6° torque lower bracket prescription is recommended. Both archwires should be in stainless steel and cinched back to prevent space opening. A palatal arch is also inserted to prevent the molars from tipping labially.

A prospective study to evaluate the short- and long-term effects of the TFBC has been part of two thesis projects at the Department of Orthodontics at the University

of Connecticut (61, 310). Twenty young female or male patients between 11 and 16 years of age with a Class II malocclusion, who underwent TFBC therapy for 3 months followed by an additional 4-month period involving seating of the occlusion with intermaxillary elastics, were evaluated at TFBC removal and end of treatment for skeletal and dental changes. The treatment sample was compared with matched controls for skeletal age and gender from the Bolton Growth Study with Class II and Class I malocclusions.

Lateral cephalograms were taken pre appliance (T1), post appliance (T2) and after deband (T3). Patients maintained the appliance for an average 3-month period. After removal of the appliance the patients were instructed to wear Class II elastics for a 3-month period from upper canine and first premolars to lower first and second premolars in order to maintain Class II correction and allow a proper interdigitation of the posterior occlusion.

Treatment changes over the different treatment periods (T1-T2, T2-T3, and T1-T3) were evaluated.

Results showed that in the T1-T2 period, upper molars were distalized and intruded while lower molars were mesialized and extruded. Upper incisor inclination decreased while lower incisor proclination and intrusion were evidenced. Mean overjet was reduced. The occlusal plane showed a clockwise rotation. The skeletal convexity of the treatment group was reduced 1.7° compared to a 0.3° reduction in the controls. A point moved posteriorly and inferiorly while B point moved only inferiorly. Mandibular length increased 2.1 mm in the study group compared to 0.7 mm for the control group. Vertical height was slightly increased. There was a significant reduction in the upper lip protrusion and increase in the nasolabial angle.

In the T2-T3 period, upper molar positions were remained but lower molars moved inferiorly. The maxillary incisors proclined while lower incisors retroclined. Overjet increased. The occlusal plane relapsed in a counterclockwise direction. Skeletal convexity was reduced. A point moved superiorly while B point anterior and superior change. Mandibular length increased 1.8 mm compared to 0.3 mm in the

experimental group. Vertical height decreased. Nasolabial angle was decreased and lower lip was retruded.

Considering the changes in the T1-T3 period, upper molars moved posteriorly and superiorly while lower molars showed an anterior and inferior movement. Upper incisors proclined and extruded while lower incisors flared. Overjet was reduced. The occlusal plane rotated in a clockwise direction. A significant reduction in the skeletal convexity of 3.7° in the experimental group compared to 0.8° in the control group. A point was positioned more posteriorly while B point showed an anterior displacement. No significant difference in maxillary and mandibular length was found between groups.

Vertical dimension increased slightly. The only small significant soft-tissue change was the upper lip protrusion reduction.

The molar correction was achieved by both dental (64%) and skeletal (36%) changes.

TFBC introduces a series of advantages over other types of fixed functional appliances (274).

It allows mandibular freedom for lateral movements for patient comfort. Additionally, from the mechanical point of view, it introduces an oscillating force through the incorporation of a coil spring within the cylinder/plunger system. Mao (203) has stated that the use of cyclic forces as opposed to static forces induces more sutural growth when comparing peak magnitude and duration.

Another advantage is that it allows alteration of the vector of the intermaxillary force to a certain degree. The force vector can be altered within the interbracket distance between the first molar and second premolar in the upper arch and the canine and the first premolar in the lower arch.

4.5.2.1.2.4.6. Ritto Appliance

The Ritto appliance ® (KS 2400-194 Leiria, Portugal) is recommended for correction of Class II malocclusion with mandibular deficiency in mixed or permanent dentition using only conventional bands on the upper molars and two tubes on the lower molars with brackets on the lower incisors (304, 305, Ritto AK. (1999). The Ritto Appliance–a new fixed functional device. *Orthodontic CyberJournal*, Available online at: www.oc-j.com).

The Ritto Appliance can be described as a miniaturized telescopic device with simplified intraoral application and activation. It has been developed over a 12-year period with the goal of creating an efficient appliance with a telescopic action that is both miniature and versatile. It is supplied in a single format, which allows it to be used on both sides, and it is available in only two sizes.

The appliance does not come apart (no disengagement after achieving maximum extension) which provides enormous advantages: it eliminates the time lost in measuring length before fitting. This facility makes it possible to fit the appliance in around 5 minutes and only about half that time is required to remove it. This also contributes to the avoidance of posterior impingement of the cheek. The smaller size facilitates adaptation, it is simple to use, comfortable, cost-effective, fracture resistant, it does not affect esthetic appearance or speech and requires no patient cooperation.

Fixing accessories consist of a steel ball-pin and a lock. Upper fixing is carried out by placing a steel ball-pin into the tube 0,045'' from the upper molar band crossing the appliance, which is then totally bent over. With this fixation the patient can perform lateral movements without limitation. The appliance is fixed onto the lower arch, which has to be prepared before insertion. The thickness and type of archwire are chosen, its length is adjusted, locks are fitted and Ritto Appliance is then inserted. The size of the lower archwire should be a 0,017''× 0,025'' stainless steel, which should be replaced every 3-4 weeks, with a 0,022'' lower tube slot and a 0,018'' lower incisor bracket slot. Activation is achieved by sliding the lock along

the lower arch in the distal direction and then fixing it against the Ritto Appliance (269).

According to Ritto, it is necessary to prepare the patient for 1-2 months before fitting the appliance so as to stimulate the musculature and avoid the patient exerting too much force on the support systems, thus fracturing them or originating unwanted dental movement. For this reason, he advises the use of a mini stimulator for mandibular advancement. This is a thermoformed splint of 0.7 mm in thickness, used only for the upper incisors constructed with the mandible in a forward position. For the first 15 days or 1 month, the patient should wear the splint for as long as possible and maintain the lower incisors fitted into the bite block. In the following weeks, the patient should start to carry out swallowing exercises with lips in contact and with incisors against the bite block. Only after this stage he starts therapy with the Ritto Appliance. After the application of the appliance it is maintained for about 6 months till Class I relation is achieved (269).

Case reports performed by Ritto with Ritto appliance therapy showed that maxilla rotated posteriorly, and the mandible anteriorly. The upper incisors inclined to palatine and the lower incisors inclined to vestibular. Regarding the soft-tissues, the profile was improved and the patient could close her lips without muscular contraction at rest position. He stated that in the retention period the treatment effects remained stable, the overjet did not relapse, the overbite increased, and the intercuspation remained unchanged, with all teeth well aligned and in good contact (269).

4.5.2.1.2.4.7. Mandibular Anterior Repositioning Appliance (MARA™)

MARA was created by Dr. Douglas Toll, of Germany in 1991. It consisted of cams on the molars, which guided the patient to bite into Class I. The appliance was low in bulk and easily tolerated by the patient. Dr. Eckhart, of the United States and Dr. Toll began experimenting with ways to improve the appliance's reliability and to provide greater flexibility in adjustment. By 1995 with the help of Ormco and AOA laboratory, a new design was provided for clinical trials (Maria Allen-Noble P.

(Access date: March 3, 2010). Clinical management of the MARA, Part 1: Introduction of the MARA. *Orthod CYBER Journal*, http://www.oc-j.com/2-99/mara1.htm).

Since it is the common way that posturing the mandible downward and forward on the articular eminence and leaving it there as a method of treating Class II malocclusions, this is not what the MARA is intended to do. The goal of MARA treatment is that the mandibular condyles, although displaced anteriorly and downward initially, eventually will be relocated in the approximate centers of the fossa (271).

Normally, a MARA consists of (204):

1. Four crowns on the first molars.

2. The lower arms soldered to the crowns.

3. Archwire tubes for the upper and lower arches soldered to the crowns.

4. Upper elbow tubes soldered to the crowns.

5. Upper elbows shimmed to provide the desired advancement.

6. Lower lingual arch soldered to lower crowns (recommended but optional.) A lingual arch is useful because the upper elbows will have a tendency to cause the lower molars to rotate and tip mesial lingual, thus crowding out the second bicuspids.

If a lingual arch is not incorporated into the appliance design, it is recommended that lower incisor brackets with negative 5-10 degree torque along with an archwire with step bends mesial to the lower molars be placed to stabilize the lower molars.

7. Other rotation and tip modalities include direct bonding to adjacent teeth, or lip bumpers.

In essence, it is an ingenious way to encourage patients to keep their mandibles thrust forward to avoid intentionally created, buccaly placed occlusal interferences. These interferences are produced when a horizontally adjustable vertical bar attached to the buccal surface of a maxillary first molar stainless steel crown hits a buccaly

protruding horizontal bar extending from the lower first molar crown. Additional activations can be made by placing one or more shims at the mesial aspect of the horizontal bar. These vertical extensions or guides function similarly to those described earlier for a removable functional appliance first reported by Clark (72).

There are several advantages to the MARA (204):

- The patient's profile immediately looks better after the appliance has been inserted.
- Class II malocclusions are treated more efficiently making treatment much easier on the orthodontist, staff, patients and parents.
- The MARA gives an immediate distal movement to the upper first molars and a simultaneous mesial to buccal rotation. (Note: at the appropriate time these movements will need to be stopped.)
- Stainless steel crowns are easier to fit, stronger, less expensive and have more retention than bands.
- There are no removable parts, thus cooperation is an issue; treatment time is predictable.
- Breakage is minimal and hygiene is not a problem
- Orthodontic appliances can be worn in conjunction with the appliance.

The disadvantages of the MARA include the following:

- Temporary stainless steel crowns needed on all first molars.
- Some increase in anterior face height results from the placement of these crowns.
- Fabrication only available at one commercial laboratory.
- The posterior and buccal location of the guide planes may cause loosening of the stainless steel crowns or breakage of the mandibular protruding horizontal bar.

TMD symptoms have not been reported from the design or advancements of the MARA and do not seem to be an issue. As with the Herbst, the MARA is frequently

used to relieve TMD symptoms, and is useful to recapture anteriorly displaced discs and to unload the joints (204).

Requirements that Effect MARA Placement:

1. The patient may present with a very small vestibule and not have enough room in the back cheek area to accommodate the MARA's lower arm and upper elbow placed on the crowned permanent first molars. In this case wait until the patient is older. *Don't treat patients too young.* Late mixed dentition all the way through advanced adulthood is appropriate.

2. The first molars must be well erupted. No operculum should cover the distal of the lower first permanent molar. *It is not recommended to place the MARA on primary teeth because the long lever arms may resorb deciduous roots.*

3. Make sure the maxilla is wide enough. Check that the upper and lower arches are coordinated when the mandible is placed in the advanced position. If not, expansion of the upper and/or lower arches may be indicated before the MARA is inserted.

4. The upper incisors should be uncrowded, properly torqued, and intruded if necessary, so they can serve as references for where to move the lower incisors.

5. Don't advance severe Class II patients too far initially. The patient will find it difficult to function in the advanced position and the appliance may lock up.

The goal is to advance the incisors to end-to-end incisal relationship overcorrecting because some relapse is expected. *A medium 4-5mm Class II* can be advanced the entire 4-5mm initially. *A severe 8-9mm Class II* should be advanced half way (4-5mm) at first. Hold the patient at the half way advancement for about 6 months. Final advancement should be to the end-to-end incisal relationship and held for an additional 6 months (204). The MARA should have been in place without any advancement or repair for 4 months immediately prior to removal, in order to have confidence that the condyles are centered in the fossa and stable (271).

The study of Pangrazio-Kulbersh et al (267) showed that the treatment effects of the MARA are quite similar to the effects of the Herbst. A group of 30 children treated for 10.7 months, when compared to similar untreated controls, was found to have experienced 2.4 mm distal upper molar movement, 0.7 mm mesial lower molar movement, 0.0 mm posterior upper jaw movement, and 2.7 mm anterior lower jaw movement. Class II molar correction was obtained by a 47% skeletal and a 53% dental change. The skeletal changes indicated that the MARA produced increases in mandibular length and in posterior and anterior face heights but had no headgear effect on the maxilla.

4.5.2.1.2.4.8. Forsus

The American orthodontist Bill Vogt from Philadelphia has made a new development in the fixed Class II appliance systems with his Forsus™ Nitinol Flat Spring (FNFS) in 2001 (140). This comprises a 0.5 × 3.0 mm spring bar (45% nickel, 55% titanium) with a transparent plastic coating. Via its bent ends the spring can be attached to bands and archwires of the previously placed fixed orthodontic appliances.

The FNFS is supplied in four different lengths: 28 mm, 31 mm, 34 mm and 37 mm, in each case for right and left fitting. Measurements are made in habitual occlusion mesially from the headgear tube of the upper first molar distally to the bracket of the lower canine. 12 mm is added to this measurement (4 mm play, 4 mm headgear tube, 4 mm activation) and this gives the length of the module to be used.

Attachment is as for the Jasper Jumper. A ball pin serves to attach it to the maxillary headgear tube. A bayonet bend is placed in the mandibular arch distal to the canine bracket and a ball stop is pushed onto it to form a stop for the FNFS. The ball pin and ball stop are both made of stainless steel. The bracket on the lower first premolar is removed so that the spring can slide along the whole archwire. Alternatively, a bypass sectional archwire can also be used for this purpose.

The FNFS keeps the mandible permanently in a forward position.

Another version of Forsus™ spring was introduced by Vogt in 2006 named Forsus Fatigue Resistant Device (FRD) (374) which is an interarch push spring that produces about 200g of force when fully compressed. Since the Forsus springs are rarely fully compressed, however, they are comparable in force level to heavy Class II elastics. Unlike other push-spring appliances, such as the Herbst, the FRD can intrude the maxillary first molars and thus correct a Class II malocclusion without opening the bite. Even in severe cases, the FRD can be used as successfully as the Herbst, which appears to provide no long-term orthopedic benefits.

The distal end of the FRD's push rod inserts into the telescoping cylinder, and a hook on the mesial end is crimped directly to the archwire near the canine or premolar brackets. The telescoping cylinder consists of inner and outer sliding tubes surrounded by an open-coil spring. An eyelet at the distal end of the cylinder is connected to the maxillary molar headgear tube with an L-pin.

The push rod has a built-in stop that compresses the spring when the patient's mouth closes. The spring force is then transferred to the maxillary molars, using the mandibular arch as the anchorage unit. Since the appliance was introduced, a recurved portion has been added to the push rod adjacent to the crimpable hook. The new parts are called Direct Push Rods because they allow the appliance to be attached directly to the mandibular archwire instead of a bypass wire. The recurved portion prevents the push rod from rotating into the bite.

The first step is to insert an L-pin into the eyelet of the telescoping spring, making sure the ball of the L-pin is facing buccally. The L-pin is then threaded through the molar headgear tube from distal to mesial and cinched, leaving about 2mm of slack.

The push rods come in four sizes, plus a customizable model that can be used for patients with extremely small or large mouths. The clinician can thus select the push rod that will deliver the optimum force level, regardless of the size of the mouth. The push rod used on the right can be a different size from the one on the left, providing more flexibility in asymmetrical cases. A measuring device is included in the appliance kit.

To deliver about 200g of force, the open coil spring should be almost fully compressed when the push rod is inserted into the cylinder and the patient closes. If a push rod is too short, it may disengage from the cylinder when the patient opens wide. If it is too long, it will fully compress the spring, which will then reposition the mandible in a forward position, like a functional appliance. This may increase the load on the canine bracket to the point that it debonds.

Once the correct size is chosen, the push rod is inserted into the telescoping spring, and the mesial hook is looped over the mandibular archwire and crimped shut. A nearly full-size rectangular mandibular archwire should be used, and it should be cinched or tied back to limit mandibular incisor flaring. Therefore, the mandibular anterior teeth must be aligned before placing the Forsus springs.

Because the open-coil spring can be compressed about 10mm, the FRD is capable of moving the maxillary molars a substantial distance over a long period of time. To keep the force level around 200g, the device can easily be reactivated by adding a crimpable stop distal to the built-in stop on the push rod.

Apart from FRD L-Pin module, FRD EZ Module and EZ2 Module are also available in the market. (http://solutions.3m.com/wps/portal/3M/en_US/orthodontics/Unitek/solutions/class-II/Forsus/)

The Forsus EZ Module provides a clip that “clicks” easily into a standard buccally-offset occlusal headgear tube by simply inserting it with any Weingart style pliers. Mesial and distal stops on the clip assure a secure fit.

The easy-to-install, "click-in-place" clip of the Forsus EZ2 Module is the latest innovation in the development of the Forsus™ springs. With the Forsus EZ2 Module, one has a fixed device that installs easily and resists breakage once engaged. The strength and security of the Forsus EZ2 Module is complemented by its design for patient comfort. A stability plate that fits under the headgear tube prevents the Forsus EZ2 Module from "rolling" and causing patient discomfort due to soft-tissue irritation. The telescoping spring fits perfectly with current appliance system.

Heinig and Göz (140) used the Forsus spring over a period of 4 months to treat 13 patients with an average age of 14.2 years with Class II malocclusion. Evaluation of the lateral cephalograms showed that dental effects accounted for 66% of the sagittal correction. The sagittal occlusal relations were improved by approximately 3/4 of a cusp width to the mesial on both the right and left side as a result of distal movement of the upper molars and mesial movement of the lower molars. Retrusion of the upper and protrusion of the lower incisors reduced the overjet by 4.6 mm. Intrusion and protrusion of the lower incisors reduced the overbite by 1.2 mm. The occlusal plane was rotated by 4.2 degrees in clockwise direction as a result of intruding the lower incisors and the upper molars. The maxillary and mandibular arches were expanded at the front and rear during treatment. Evaluation of a questionnaire filled in by the patients after 2 months of treatment showed that approximately half of them had experienced difficulties in brushing their teeth. The main problem, however, was the restriction experienced in the ability to yawn. Overall, two thirds of the adolescents found the Forsus spring better than the appliance previously used to correct their Class II malocclusion, such as headgear, activator or Class II elastics.

Karaçay et al (175) compared the effects of FNFS and Jasper Jumper in the correction of Class II Division I malocclusions on 48 adolescents, who had a normal or horizontal growth pattern and retrognathic mandible. The patients were divided into three equal groups randomly. First group was treated with FNFS, and the second group was treated with JJ appliances, whereas the third group was the control group. Lateral cephalograms and study models were obtained after the leveling phase and at time of the removal of the appliances. Cephalometric analysis revealed that both the appliances stimulated mandibular growth, increased the anterior face height because of the lower face, and elongated the posterior face height because of the growth of temporomandibular joint. Maxillary central incisors were extruded, retruded, and distally tipped. Contrarily, intrusion, protrusion, and labial tipping were observed in the mandibular central incisors. Distal movement and intrusion of the maxillary first molars and mesial movement and extrusion of the mandibular first molars were the other dental alterations. Overjet and overbite were decreased, and a Class I molar relationship and improvement in the profile were attained in both treatment groups.

Cast model analysis showed expansion in the maxillary and mandibular dental arches. They concluded that both the appliances were effective in the treatment of Class II malocclusion and revealed nearly same alterations in the skeletal, dental, and soft-tissue parameters.

El-Sheikh et al (98) performed an in vitro study about FRD. The aims of the study were: (1) to measure the mean force delivered at different amounts of deflection; (2) to determine and compare the mean stiffness between loading and unloading; and (3) to determine the resilience of the fatigue-resistant device springs. Twelve fatigue-resistant device springs were tested with a universal testing machine and Winrcon software, with the load cell of 100 N, crosshead speed at 0.5 mm/second. Force-deflection data during loading and unloading were recorded at 2-mm intervals up to 12 mm compression. Results showed that (1) The mean force-deflection loading and unloading curves generally were linear, with a small area of hysteresis; (2) the loading mean stiffness (19.4 g/mm) was significantly greater than the unloading mean stiffness (18 g/mm), although this is clinically insignificant; (3) fatigue-resistant device springs exhibited good resiliency.

Jing et al (169) treated 18 mandibular retrognathy cases with Forsus™ and found the appliance effective improving the profile. B point moved forward 2,9 mm.

Jones et al (173) evaluated the Forsus Fatigue Resistant Device as a compliance-free alternative to Class II elastics. A sample of 34 (14 female, 20 male) consecutively treated nonextraction FRD patients (12.6 years of age) were matched with a sample of 34 (14 female, 20 male) consecutively treated nonextraction Class II elastics patients (12.2 years of age) based on four pretreatment variables (ANB, L1-GoMe, SN-GoMe, and treatment duration). Pretreatment and posttreatment cephalometric radiographs were compared. No statistically significant differences were found in the treatment changes between the groups. There was a general trend for mesial movement of the maxilla, mandible, and dentition during treatment for both groups. The mandibular skeletal advancement and dental movements were greater than those in the maxilla, which accounted for the Class II correction. Lower incisor proclination was evident in both groups. Vertically, the maxillary and mandibular molars erupted during treatment in both groups, while lower incisors

proclined. With the exception of lower molar mesial movements and total molar correction, which were significantly greater in the Forsus group, there were no statistically significant group differences in the treatment changes.

Arici et al (10) tested the hypothesis that fixed functional appliance treatment in a group of Class II Division 1 patients with mandibular retrusion changes the condyle position in the glenoid fossa by using Forsus nitinol flat-spring. Transverse computed tomography images were taken of the temporomandibular joint region in 60 children with Class II Division 1 malocclusion. Thirty randomly selected patients were treated with FNFS for 7 months; another 30 patients without treatment were used as controls. Computed tomography images taken at the beginning and end of fixed functional appliance treatment were used for estimating the condyle-glenoid fossa relationship, including the volumes of condyle, glenoid fossa, and anterior and posterior joint spaces. Results showed that although the volumes of the condyle and glenoid fossa increased more in the study group than in the control group, the differences were not statistically significant. However, statistically significant differences were found between the groups in the volumes of the anterior and posterior joint spaces. They concluded that when the volumes of the anterior and posterior joint spaces changed, the condyle was more posteriorly positioned in the glenoid fossa in the study group than in the control group.

Short-term effects of the FRD L-Pin Module have been part of a thesis project at the Department of Orthodontics at the Yeditepe University (125).

15 young female or male patients between 13 and 17 years of age with a Class II malocclusion who underwent FRD therapy were evaluated. The treatment sample was compared with a control group consisting of 12 patients in the period of same skeletal age. The appliance was kept in the mouth for 5 months till Class I relation was achieved. Lateral cephalograms and study models were obtained after the leveling phase and at time of the removal of the appliances in the treatment group and in the beginning and after 6 months in the control group. TPA was applied all patients. 0,022'' slot brackets were used and FRD was applied after passing 0,019×0,025'' stainless steel wires. No growth restriction in the maxilla was observed. Vertical distance remained stable. Uprighting and extrusion in the upper

incisors and proclination and intrusion in the lower incisors were noted. Occlusal plane was rotated in the clockwise direction. Overjet and overbite was reduced. An improvement in the soft-tissue profile was achieved.

4.5.2.1.3. Interarch Elastic Traction

Interarch traction from the anterior part of the maxillary arch to the posterior part of the mandibular arch, commonly referred to as Class II elastics, is intended to deliver an anterior force to the mandibular teeth and a posterior force to the maxillary teeth. This results primarily in protraction of mandibular teeth and, to a lesser extent, retraction of maxillary teeth. Although these dental movements usually are desirable with Class II elastics, there are other simultaneous dental movements that clinicians usually attempt to limit as much as possible. Because of the vertical vector of force that accompanies the use of Class II elastics, some extrusion of mandibular posterior and maxillary anterior teeth is to be expected. This results in rotation of the occlusal plane up posteriorly and down anteriorly. In addition, because of a slight force in the transverse dimension, there is some tendency for mandibular molars to tip buccally (35).

The most appropriate indication for the use of Class II elastics is where anterior movement of the mandibular teeth is desired and rotation of the occlusal plane with extrusion of mandibular molars and maxillary incisors is not detrimental to the treatment outcome. The most ideal circumstance for treatment with Class II elastics is a dental Class II malocclusion in the presence of a normal skeletal jaw relationship. A final favorable indication would include at least some minimal mandibular growth potential with flat occlusal and mandibular planes where an increase in lower face height is desired. If space were present in the dental arches, it would be preferable for the space to be mesial to the mandibular molars and distal to the maxillary molars (35).

The use of Class II elastics should be limited to the permanent dentition with a complete fixed orthodontic appliance and continuous arch wires in place. Because the effects of Class II elastics are limited to dental movement with no appreciable

influence on the skeletal relationship, their use before eruption of the premolars and canines would be contraindicated in most cases. There is a second important reason for not using interarch traction with only partial eruption of the permanent teeth. The vertical forces associated with Class II elastics tend to extrude the maxillary incisors and the mandibular molars. If the fixed appliance is only in place on the first molars and incisors, there is a much greater extrusive effect because of the absence of adjacent teeth that can serve to reinforce anchorage or resistance to the unwanted extrusive tooth movement (35).

Numerous clinical studies demonstrate that the effects of Class II elastics are limited to the dentition (173, 234, 235).

Nelson et al (235) compared dentofacial morphology and long-term follow-up changes in growing males with skeletal Class II malocclusions treated without extractions and with either Class II elastics or Herbst appliances. Treatment effects differed between the groups, with usually more favorable effects in the Herbst group. However, during the follow-up period, many of the changes were reversed. During the total observation period, maxillary prognathism and lower anterior facial height increased more in the Class II elastics group than in the Herbst group. As a conclusion, although there were initial marked differences in the treatment outcomes, most of these differences were not sustained over the longer term.

4.5.2.2. Dental Camouflage

The goal of dental camouflage is to disguise the unacceptable skeletal relationship by orthodontically repositioning the teeth in the jaws so there is an acceptable dental occlusion and esthetic facial appearance. The primary dental movement needed is retraction of maxillary teeth and protraction of mandibular teeth to eliminate overjet and correct buccal occlusion. Individuals who already have extensive natural dental compensation present before treatment with the mandibular incisors in a protrusive position are poor candidates for dental camouflage because dental camouflage is aimed at creating or accentuating dental compensation for the skeletal discrepancy (35).

The characteristics of a patient who would be a good candidate for camouflage treatment are (235):

• Too old for successful growth modification

• Mild to moderate skeletal Class II

• Reasonably good alignment of teeth (so that the extraction spaces would be available for controlled anteroposterior displacement and not used to relieve crowding)

• Good vertical facial proportions, neither extreme short face (skeletal deep bite) nor long face (skeletal open bite)

Conversely, camouflage treatment designed to correct the occlusion despite jaw relationship problems should be avoided in (295):

• Severe Class II and vertical skeletal discrepancies,

• Patients with severe crowding or protrusion of incisors, in whom the extraction spaces will be required to achieve proper alignment of the incisors,

• Patients with excellent remaining growth potential (in whom growth modification treatment should be used) or non-growing adults with more than mild discrepancies (in whom orthognathic surgery usually offers better long-term results).

The types of dental camouflage for Class II skeletal problems can be divided conveniently according to whether or not the treatment requires extraction of teeth (35).

4.5.2.2.1. Dental Camouflage without Extractions

The goals of nonextraction treatment are to retract the maxillary dentition and protract the mandibular dentition to the extent that overjet is eliminated and normal posterior occlusion is achieved. When adequate generalized spacing in the arches is not present, it may be difficult but possible to move maxillary posterior teeth distally

to create sufficient space to retract maxillary teeth. This requires bodily distal movement of maxillary molars. Traditionally, the only possible method was full-time use of extraoral force with a facebow attached to the first molars. Successful distal molar movement requires full-time headgear wear, and appreciable movement is possible only if the second molars are not present. If patient compliance is inadequate, the only other option is to place an orthodontic appliance that delivers an intraoral distal force to the maxillary molars (35).

The most common molar distalization appliances are:

1. Pendulum Appliance (145)
2. Distal Jet (62)
3. Jones Jig (172)
4. Intraoral Bodily Molar Distalizer (177)
5. Repelling Magnets (44)
6. The First Class Appliance (106)

Unfortunately, intraoral forces always have a reciprocal reactive force affecting the other teeth that is usually counterproductive to the orthodontic treatment. If the intraoral distal force to the maxillary molars is generated by a spring, the reactive force is an equal mesial force to the maxillary anterior teeth, moving them in the opposite direction desired (35).

4.5.2.2.2. Dental Camouflage with Extractions

It is usually necessary to extract maxillary first premolars when treating a Class II malocclusion with dental camouflage to gain sufficient space to retract maxillary canines and incisors. Adequate space is available only if there is no excessive protrusion of maxillary incisors. Furthermore, if there is no appreciable crowding or protrusion of the mandibular incisors, no mandibular extractions are necessary. The treatment goal in this instance is to maintain the molars in a Class II relationship but achieve complete reduction of the overjet. Another approach to dental camouflage with extraction is to extract mandibular first or second premolars as well as maxillary

premolars. The treatment goal in this instance is to use the extraction space to move the mandibular posterior teeth forward into a normal molar relationship. If there is preexisting crowding or protrusion of the mandibular incisors, mandibular extractions are essential (35).

In 1994 Proffit investigated the rate of extraction treatment between 1953 and 1993 in a review of consecutive charts at 5-year intervals from the orthodontic clinic at the University of North Carolina. The number of patients with extraction of all four first premolars increased from 10% in 1953 to 50% in 1963, remained at 35% to 45% until the early 1980s, then declined sharply to the 1950s level by 1993. Extraction for camouflage of Class II malocclusion reached 16% in 1968, then declined, but not as dramatically, and presently is as frequent as the extraction of four first premolars. The rate of extraction of other teeth, done for a variety of individual reasons, has remained almost constant at about 15% for the past 40 years. Thus the total extraction percentage was 30% in 1953, peaked at 76% in 1968, and declined again to 28% in 1993, with almost all the change in the percentage of four first premolar extractions. He concluded that the increase in first premolar extractions occurred primarily in a search for greater long-term stability; the recent decline seems due to a number of factors. Greater concern about the impact of extraction on facial esthetics, data to suggest that extraction does not guarantee stability, concern about temporomandibular dysfunction, and changes in technique all seem to have played a role (292).

Janson et al (163) compared the postretention stability of the correction of mandibular anterior-tooth irregularity in patients with Class II malocclusions whose orthodontic treatments included extraction of 2 or 4 premolars. They concluded that treatment of Class II malocclusion with extraction of either 2 maxillary premolars or 4 premolars provides the same mandibular anterior-tooth alignment stability. It was also reported that treatment time will be shorter and the occlusal results more predictable with a 2-premolar extraction protocol compared with 4 premolar extractions (166).

In another study Janson et al (164) compared the initial occlusal and cephalometric severity of Class II Division 1 malocclusion patients treated with and

without extraction of 2 maxillary premolars and they concluded that for patients with more severe anteroposterior discrepancies, an extraction plan provides more effective treatment with less need for patient compliance.

Some investigations claimed that excessive retraction of incisors in upper premolar extractions leads to backward position of condyle and temporomandibular dysfunction occurs (165, 191, 391). Controversially In 1992, Luecke and Johnston showed that premolar extraction and incisor retraction do not lead to unsightly profiles and distal mandibular displacement (199).

Similarly some of the other investigators reported that the condyle is anteriorly positioned in the glenoid fossa while the upper incisors are retracted and there is no correlation between extraction protocol and temporomandibular disorder (27, 118, 119, 275).

Boley et al (46) performed a study to determine if there are any differences in the posttreatment faces of patients treated nonextraction and those treated with premolar extraction in properly diagnosed and treated cases. The study was conducted in two parts. In Part 1, perceptions of 192 experienced general dentists and orthodontists were tested. Facial photos of 25 consecutively treated nonextraction patients and 25 consecutively treated four-premolar-extraction patients were shown to the study participants. They were asked if the patient was treated with the extraction of four premolars or without extractions. In Part 2, profiles were evaluated based on cephalometric tracings. It was concluded that experienced orthodontists and general dentists could not determine whether treatment was nonextraction or extraction by looking at the face alone. Also, there was no significant difference between the faces produced by the two types of treatments.

Bowman et al (49) compared the esthetic effects of extraction and nonextraction treatments. Panels of 58 laypersons and 42 dentists evaluated randomly presented pre- and posttreatment profiles of 70 extraction and 50 nonextraction Class I and II Caucasian patients. The samples were similar at the outset; however, at the end of treatment, the extraction patients' faces were, on average, 1.8 mm ''flatter'' than the faces of nonextraction subjects. The flatter faces were preferred by both panels,

dentists more so than laypersons. In general, nonextraction treatment was seen as having little effect on the profile, whereas the perceived effect of extraction treatment was a statistically significant function of initial soft-tissue protrusion—the greater the initial protrusion, the greater the benefit. It was concluded that extraction treatment can produce improved facial esthetics for many patients who present with some combination of crowding and protrusion.

Conley and Jernigan (81) evaluated the effect of maximum retraction in skeletal mandibular deficient Class II patients with essentially no crowding. Twenty-seven Class II Division I Caucasian patients with a mean of 8.62 mm of overjet, little to no arch length deficiency, and maximum anchorage requirements were treated with extraction of only maxillary first premolars. Pre- and posttreatment lateral cephalograms were taken and the treatment changes were assessed. The mean maxillary incisor retraction was 5.27 mm, the mean maxillary lip retraction was 2.03 mm, and the mean mandibular lip retraction was 1.23 mm. All the patients finished with good overall facial harmony and balance. They concluded that the maxillary first premolar extraction for orthodontic camouflage may be a viable treatment option, especially if the patient has full upper lips and only a relative mandibular deficiency. Most notably, labrale superius and labrale inferius were retracted, the lower facial height increased mildly, and the nasolabial angle became more obtuse. Maxillary incisor retraction to labrale superius retraction occurred at a 2.68:1 ratio.

The effect of extraction on vertical dimensions is also discussed for many years. Some of the authors claim that the anterior tipping of the posterior teeth leads to an anterior rotation of the mandible leading to reduction on vertical dimension (280, 326, 333).

Some of other investigators showed that the changes in horizontal and vertical position of the molars were dependent on the type of force application but not on extraction/nonextraction procedures. It is necessary to control the vertical position of maxillary and mandibular molars during treatment or their extrusion can nullify the desirable effects of mandibular growth (81, 392).

Meral et al (216) evaluated the effects of bilateral upper premolar extraction on mandibular growth. They showed that the mean anterior rotation in the extraction group was not significant whereas the control group showed anterior mandibular rotation.

4.5.2.3. Orthognathic Surgery

There are many skeletal Class II problems in individuals with little or no remaining growth potential that cannot be treated properly with orthodontic treatment alone. This can be the case if at least one of two features is present with the malocclusion. The first is that the skeletal disharmony is so severe that the extent of dental movement (maxillary retraction or mandibular protraction) necessary to eliminate the overjet is either too great to permit a stable treatment outcome or too great to permit an esthetic facial result. The second feature that precludes acceptable dental camouflage treatment is the presence of crowding or protrusion of incisors that is severe enough to require all of the lower extraction space to correct these problems, leaving no additional space to retract maxillary teeth or protract mandibular teeth (35).

Originally developed in Europe, orthognathic surgical techniques were further advanced in the United States during the 1960s and 1970s. By the 1980s it was possible to reposition the jaws or dentoalveolar segments in all three planes of space. The adoption of rigid internal fixation during the 1980s provided further progress in the management and stability of orthognathic surgical treatment. At the end of the twentieth century, facial skeletal problems can be treated directly at the source of the malocclusion with surgical correction of the specific jaw discrepancy or disproportion at fault. In terms of Class II skeletal malocclusions, the surgical treatment options are at least as abundant as the underlying causes of the problems (35).

Surgical correction implies that the mandible is advanced to a Class I skeletal jaw relationship by either sagittal split osteotomy or mandibular distraction osteogenesis. Mandibular sagittal split surgery is generally confined to the

nongrowing patient and done after Radius union at the age of 18 to 20 years. Distraction osteogenesis is performed in adults and children. However, relapses in children may occur when craniofacial growth is not completed at the time of therapy (253).

4.5.3. Timing of Class II Malocclusion Treatment

The timing of treatment for Class II malocclusion remains a controversial clinical issue despite the considerable volume of literature on this topic over the last years. Clinical decisions such as the optimal time to start treatment are inevitably difficult because of the variability between patients and the uncertainty about growth and treatment response (299).

Ideally, treatment would be provided when it is most effective and most efficient. The debate is not really whether Class II malocclusion can be corrected at various times in a child's development; there is ample evidence from clinical practice that it usually can. Rather, the question should be whether early treatment, which is almost always followed by a second phase of treatment, provides superior results to conventional treatment started in the permanent dentition, and, if it does, is there enough additional benefit to justify the almost inevitable greater burden of treatment for patients, parents, and practitioners? (299).

Proffit (299) implies that several important factors play into the choices about the optimal timing of orthodontic treatment for patients with Class II malocclusion, and these largely relate to the uncertainty about growth and treatment response. The majority of patients with moderate to severe Class II occlusal problems also have some type of skeletal imbalance. Thus, early treatment to modify growth might allow subsequent treatment to correct the alignment and the occlusion of permanent teeth to proceed more quickly or by simpler methods. This argument raises 3 critical issues:

(1) Can jaw growth really be modified, and if so, by how much, with what predictability, and in which patients?

(2) Do different appliances produce different effects?

(3) Even if growth can be modified in a controlled way, what impact would early intervention have on subsequent orthodontic treatment? Would later treatment really be simpler and would the treatment results be better?

According to Bishara (32), there are significant mandibular changes in size and relationship between the ages of 8 and 17 years. The changes in mandibular relationship were not significantly different in the maximum and premaximum periods in either boys or girls. The magnitude of change in the postmaximum period tended to be smaller than in the other 2 periods. He says: because the occurrence, magnitude, and timing of the spurt in a particular patient is highly unpredictable, the treatment of anteroposterior discrepancies should be initiated as soon as the orthodontist believes that treatment is indicated and not delayed for the pubertal ''spurt''. He also adds: patient cooperation in wearing extraoral or functional appliances does not seem to improve at the later stages of adolescence. If anything, most of these patients are involved in various activities that often distract them from wearing such appliances. Actually, a study by Tung and Kiyak (366) found that there was greater cooperation in younger ages than in adolescence.

In a literature review in 1990, King et al (178) pointed out that there were no data available related to support the claims of beneficial effects of early treatment including : the final result after treatment in the teens is more stable; there is less need for the extraction of permanent teeth; and the clinician picks the time for adolescent treatment.

In a trial study at the University of North Carolina, Tulloch et al (365) selected children with overjet (OJ) greater than 7 mm who were still in the mixed dentition, at least 1 year before their peak height velocity, and who had received no prior orthodontic treatment. The sample included 175 children with a mean age of 9.4 years (range, 7.3-12.6 years) and a mean OJ of 8.4 mm (range, 7-15.5 mm). Of the 175 children starting the trial, 166 completed phase 1, and 143 started and completed phase 2; 4 children were deemed by their parents not to need further treatment, and 19 either moved from the area or withdrew from the study.

The trial was conducted in 2 phases. During the first phase, the children were randomly assigned to treatment starting in the mixed dentition, with either a combination headgear worn alone or a functional appliance (modified bionator), or to a control (observation only) group in which all treatment was delayed until the permanent dentition was established. Records were taken on all the children after they had been followed for 15 months. In the second phase of the trial, all the children were treated, and the comparison was made between those who had received early treatment and those who had not.

According to results, the distribution of categories of skeletal change, from highly favorable to unfavorable showed that more than 75% of the patients in the early treatment groups had favorable or highly favorable changes, while only about 25% of those in the control group showed similar favorable changes. The differences in distribution of response categories between the early treatment and the control groups were statistically significant. However, no reliable predictors of the magnitude or the likelihood of favorable growth changes were determined. Surprisingly, there was very little difference in the time both groups spent wearing fixed appliances. Early treatment had only a very small effect in reducing the subsequent time in treatment. The conclusion from this randomized trial was that, in most instances, there does not seem to be a clear advantage for early treatment for Class II malocclusion.

Von Bremen and Pancherz (375) assessed the efficiency of early and late Class II Division 1 treatment in the mixed and permanent dentition. They examined 204 patients treated in the early mixed dentition (n = 54), late mixed dentition (n = 104), and permanent dentition (n = 46). The duration of treatment decreased with progressing dental development: patients in the early mixed dentition were treated for 57 months, patients in the late mixed dentition for 33 months, and patients in the permanent dentition for 21 months. Patients treated exclusively with fixed appliances had shorter treatment duration than did patients treated with functional appliances or a combination of appliances. Based on the results of this investigation, they concluded that treatment of Class II Division 1 malocclusions is more efficient in the

permanent dentition (late treatment) than it is in the mixed dentition (early treatment).

Dolce et al (94) studied the effects of 1-phase and 2-phase orthodontic treatment using the centroid centrographic analysis to Phase 1 treatment consisted of bionator (n _ 66), headgear/biteplane (n _ 69), or observation (n _ 65) until a Class I molar relationship was achieved or 2 years had elapsed. After 1 year, all subjects underwent full orthodontic treatment with fixed appliances. Results showed that early treatment has effects on the mandible. However, the differences were not apparent by the end of fixed appliance treatment. They concluded that the skeletal effects of phase 1 treatment disappear by the end of fixed appliance treatment.

Recently, Dolce et al (93) performed a prospective study they evaluated a total of 260 subjects demonstrating at least a one half-cusp Class II molar relationship and meeting the inclusion criteria were enrolled in the study and had at least 1 follow-up visit. During phase 1, 86 subjects were treated with a bionator, 95 were treated with a headgear/biteplane, and 80 served as the observation group. For phase 2, all subjects were then treated with full orthodontics appliances. By the end of full orthodontic treatment, the skeletal differences in all measurements for all 3 groups were within 1°. In conclusion, there was temporary skeletal change as a result of phase I treatment with both appliances but no detectible skeletal difference between 1-phase and 2-phase treatment of Class II malocclusion by the end of full orthodontic treatment. In 2009 Wortham et al (390) compared arch dimension changes in 1-phase and 2-phase treatment of Class II malocclusion in a prospective study. They found no differences in arch dimensions.

Brin et al (52) evaluated the results of 1 phase and 2 phase treatment regarding external apical root resorption (EARR) is an imperfectly understood problem of orthodontic treatment. The proportion of incisors with moderate to severe EARR was slightly greater in the 1-phase treatment group. There was no difference in the incidence of EARR between teeth that had had trauma and those that had not, and there was only a slight increase in frequency of root resorption in teeth with unusual root morphology.

What about the effect of early treatment on the prevention of traumatic injuries to the prominent maxillary incisors in some Class II patients? It is still unclear just what treatment timing is most effective when evaluating the at-risk group in the long term. Nguyen et al (238) found that children with an overjet greater than 3 mm have twice as much risk for fracture as children whose overjet is smaller than 3 mm. On the other hand, authors of long-term 2-phase studies believe that, for treatment to be effective in preventing trauma to incisors, it would have to start very early— shortly after the eruption of the central incisors (183). Anything much later simply misses too many problems resulting from accidental trauma.

If not the risk of trauma for subjects with protruded front teeth, what about the opportunity to enhance self-esteem in young people as early as possible? Short-term studies show varying degrees of improved well-being when children and adults receive orthodontic treatment (240).

For a longer-term look, take a look to the article by researchers from the University of Manchester in the United Kingdom (339). The authors of this study concluded that a lack of orthodontic treatment when there was a prior need did not lead to psychological difficulties in later life.

The Cochrane Library has released the longawaited systematic review of the efficiency of 2-phase treatment when initiated in patients between the ages of 7 and 9 years to correct Class II malocclusions (137). The subjects were children or adolescents (age 16 or younger) who received treatment to correct prominent maxillary front teeth. Expected outcomes were (1) primary, the prominence of the maxillary front teeth and the relationship of the 2 jaws; and (2) secondary, self-esteem, any injury to these teeth, jaw joint problems, patient satisfaction, and the overall number of appointments required to complete treatment. The evidence suggests that early orthodontic treatment for children with prominent maxillary front teeth is no more effective than 1 course of treatment when the child is in early adolescence.

Justus (174) asked ''Are there any advantages of early Class II treatment?''. Two-phase treatment will undoubtedly extend treatment time and increase its costs.

Justus brings 2 additional factors to the discussion: incisal trauma and external apical root resorption. Perhaps other clinical concerns also require such ''vetting'' before departures from conventional clinical decision making are so strongly advocated or instituted.

4.5.3.1. Timing of Functional Appliance Treatment

The general opinion on this issue has been to treat Class II discrepancies during growth. However, some authors have shown that it is possible to treat such patients in late adolescent or as young adults. In 2000, Pancherz (253) stated that: *It is now time to revise the above concept in skeletal Class II therapy using age as a decisive factor should be revised when choosing between a growth adaptive or a surgical approach. This is because of the fact that research has disclosed that growth in the TMJ region can continue for many years after the age of 20 years or can be reactivated at this later age.*

Paulsen and Karle (277) investigated morphologic changes in the TMJs of two patients with Class II Division 1 malocclusion in adulthood after cessation of endochondral growth (union of the radius epiphysis) with an asymmetric sagittal molar occlusion, treated with the Herbst appliance and followed 2 years. They concluded that TMJs exhibit asymmetric, adaptive bone growth, normalizing the sagittal molar occlusion.

The main of therapy with functional appliances is to induce supplementary lengthening of the mandible by stimulating increased growth at the condylar cartilage. The effectiveness of functional treatment of mandibular growth deficiency strongly depends on the biologic responsiveness of the condylar cartilage, which in turn depends on the growth rate of the mandible (109). It is well known that the growth rate of the human mandible is not constant throughout development. A peak in mandibular growth velocity (pubertal growth support) has been described in many previous cephalometric studies (156, 230). Clinical research has demonstrated that the greatest effects of functional appliances take place when the mandibular growth peak is included in the treatment period. Hagg and Pancherz found that sagittal

growth at the condyle in patients treated with the Herbst appliance at the pubertal growth peak was twice that observed in patients treated 3 years before or 3 years after the peak (127).

Petrovic et al (287) revealed that some removable functional appliances (activator, Frankel, and bionator) are more effective when they are used during the ascending portion of the individual pubertal growth spurt. Malmgren et al (201) demonstrated significantly greater skeletal effects induced by the Bass appliance in boys treated during the peak period than in those treated in the pre-peak period. McNamara et al (209) described less dramatic changes in mandibular length in subjects who started treatment with the FR-2 appliance early to mid-mixed dentition (average age 8.8 years) than in those starting treatment during late mixed to early permanent dentition (average age 11.6 years). Baccetti et al (15) revealed that the optimum treatment timing for twin-block therapy for Class II disharmony appears to be during or slightly after the onset of the pubertal peak in growth velocity.

4.5.3.1.1. Functional Appliance Treatment as an Alternative to Orthognathic Surgery

According to Pancherz (253), the concept in skeletal Class II therapy using age as a decisive factor should be revised when choosing between a growth adaptive or a surgical approach. This is because of the fact that research has disclosed that growth in the TMJ region can continue for many years after the age of 20 years or can be reactivated at this later age. The research data he is referring to are the following:

- Behrents (28) has demonstrated that craniofacial growth may continue to a considerable extent in both males and females *after the age of 30 years.*

- Protrusion experiments in *adult monkeys* have disclosed that condylar growth can be stimulated and the glenoid fossa be remodeled (147, 387, 389).

- Histologically it has been shown that zones of unmineralized growth cartilage and undifferentiated mesenchyme are present in the *adult* mandibular condyle (65, 279).

• Observations in connection with condylar fracture therapy (195), mandibular osteotomies (150), and mandibular repositioning in disk displacement therapy (141, 327) have proven that the *adult* TMJ is capable of remodeling.

• In 2 recent well-controlled prospective longitudinal studies, Ruf and Pancherz (319, 320) have shown that *young adults* (Radius union) with Class II malocclusions could be treated successfully with the Herbst appliance. The age range was 14 to 18 years for the female and 16 to 20 years for the male patients. Mandibular prognathism was increased and the skeletal and soft-tissue profile convexity was reduced in all subjects. Magnetic resonance imaging (MRI) of the temporomandibular joints revealed condylar and glenoid fossa remodeling in almost all joints.

• In an investigation by Ruf and Pancherz (322) comparing Class II-*adults* treated successfully by either orthognathic surgery (sagittal mandibular split osteotomy) or dentofacial orthopedics (Herbst appliance), it was revealed that the hard and soft-tissue profile convexity was significantly reduced by both methods. The age range was 15 to 34 years for the Herbst and 17 to 35 years for the surgery subjects. Total treatment time (including postsurgical and post-Herbst orthodontics with multibracket appliances) was comparable in the two groups and amounted to 2 years.

• Furthermore, recent MRI-TMJ studies at our department have shown that Herbst treatment does not result in temporomandibular disorders on a long-term basis or cause any adverse changes in articular disk position (265). On the contrary, the Herbst appliance could possibly be useful in the therapy of patients with milder forms of anterior disk displacement.

Thus, Pancherz stated that: 'When considering the results from the above research and especially from recent adult Herbst studies, orthopedic growth adaptation with the use of the Herbst appliance is a useful alternative to orthognathic surgery in borderline adult skeletal Class II cases particularly when the two methods are compared with respect to costs and risks as well as to total treatment time.'

In 2004 Ruf and Pancherz (322) assessed to what extent adult Herbst treatment is an alternative to orthognathic surgery by comparing the dentoskeletal treatment effects in 46 adult Class II Division 1 subjects treated with a combined orthodontic-orthognathic surgery approach (mandibular sagittal split osteotomy without genioplasty) and 23 adult Class II Division 1 subjects treated with the Herbst appliance. Lateral headfilms in habitual occlusion from before and after treatment (multibracket appliance treatment after surgery or Herbst treatment) were analyzed. All surgery and Herbst subjects were treated successfully to Class I occlusal relationships with normal overjet and overbite. In the surgery group, the improvement in sagittal occlusion was achieved by skeletal more than dental changes; in the Herbst group, the opposite was the case. Skeletal and soft-tissue facial profile convexity was reduced significantly in both groups, but the amount of profile convexity reduction was larger in the surgery group. The success and predictability of Herbst treatment for occlusal correction was as high as for surgery. They concluded that the Herbst appliance is a powerful tool for nonsurgical, nonextraction treatment of adult Class II malocclusions. Thus, the treatment approach can be considered as an alternative to orthognathic surgery in borderline skeletal Class II subjects. For Class II correction, the success rate and predictability of Herbst treatment is as high as for orthognathic surgery. If, however, the patient's main wish is a greatly improved facial profile, orthognathic surgery is the better treatment alternative.

In 2009, Chaiyongsirisern et al (70) compared the treatment effects and long-term stability of the stepwise Herbst appliance and mandibular sagittal split osteotomy in skeletal Class II adult patients. Subjects comprised 16 patients in the Herbst group and another 16 patients in the surgery (mandibular sagittal split osteotomy) group. Lateral head films were taken before treatment (T0), after removal of the Herbst appliance/surgery (T1), after the fixed appliance treatment (T2), and 3 years after treatment (T3). All films were analyzed by standard cephalometric. All Herbst and surgery patients were treated successfully to Class I occlusal relationships with normal overjet and overbite. Both groups showed a significant change in mandibular base advancement, which resulted in a decrease in the ANB angle, the Wits appraisal, and facial convexity. However, the surgery group showed larger

changes in the parameters mentioned above. In terms of long-term stability, both groups achieved stable results, and no significant difference occurred over time. They concluded that stepwise advancement Herbst appliance therapy can be used to treat borderline skeletal Class II adult patients with long-term stability.

5. SUBJECTS AND METHOD

5.1. Subjects

5.1.1. Subject Selection Criteria

Thirty growing patients with Class II Division 1 malocclusion were selected among the patients registered for orthodontic treatment at the Department of Orthodontics, Faculty of Dentistry, University of Marmara.

Inclusion Criteria:

- Skeletal Class II and dental Class II Division 1 malocclusion,
- Normal or mildly prognathic maxilla,
- Retrognathic mandible,
- Maximal pubertal growth not yet reached,
- Normal or low angle growth pattern,
- Permanent dentition,
- Minimum crowding in the dental arches.

Exclusion Criteria:

- Syndromic condition,
- Significant dental or skeletal asymmetry,
- Skeletal openbite characteristics,
- Temporomandibular joint dysfunction,
- Previous growth modification therapy,
- Gingival recession,
- Lack of cooperation.

All the subjects and their families were given information about the project and Marmara University Health sciences Ethical Committee confirmation report was taken for the research (Date: May 2, 2008 – Number: B. 30.2. MAR. 0.01.02/AEK/396).

Based on the selection criteria, 25 patients (16 males, 9 females) (Table 1) comprised the sample while 5 of 30 patients were excluded from the study due to lack of cooperation.

Lateral cephalograms and hand-wrist radiographs were available at the start of treatment (T0), before the application of Forsus™ Fatigue Resistant Device (T1), and after the removal of appliance (T2).

The average chronological age of the sample was 11 years 10 months ± 10 months at T0; 12 years 2 months ± 12 months for males (12:2; range: 10:9 to 13:11), and 11 years 5 months ± 7 months for females (range: 10:7 to 12:5).

The average chronological age of the sample was 12 years 9 months ± 10,5 months at T1; 13 years ± 10 months for males (range: 11:11 to 14:6), and 12 years 4 months ± 9 months for females (range: 11:3 to 13:7).

The average chronological age of the sample was 13 years 7 months ± 11 months at T2; 13 years 6 months ± 12 months for males (range: 12:2 to 15:0), and 12 years 9 months ± 10 months for females (range: 11:7 to 14:0) (Table 2).

Hand-wrist radiographs were taken and interpreted according to the criteria defined by Fishman in order to assess the skeletal ages of the sample (102) (Figure 1, 2).

The average growth stage of the sample was 2,72 ± 0,84 at T0; 2,31 ± 0,79 for males (range: 1 to 4), and 3,44 ± 0,73 for females (range: 2 to 4).

The average growth stage of the sample was 4,28 ± 1,43 at T1; 3,63 ± 1,02 for males (range: 2 to 6), and 5,44 ± 1,33 for females (range: 4 to 7).

The average growth stage of the sample was 5,57 ± 2,24 at T2; 4,88 ± 1,5 for males (range: 3 to 9), and 7,33 ± 2,35 for females (range: 5 to 10) (Table 3).

The average time that elapsed between the start of the treatment and insertion of the Forsus™ Fatigue Resistant Device was 10 months 12 days ± 3 months 26 days.

The average time that elapsed between insertion of the Forsus™ Fatigue Resistant Device and achievement of a Class I or super Class I molar and canine relationship was 6 months 2 days ± 2 months 16 days.

Table 1: Sex distribution in study group

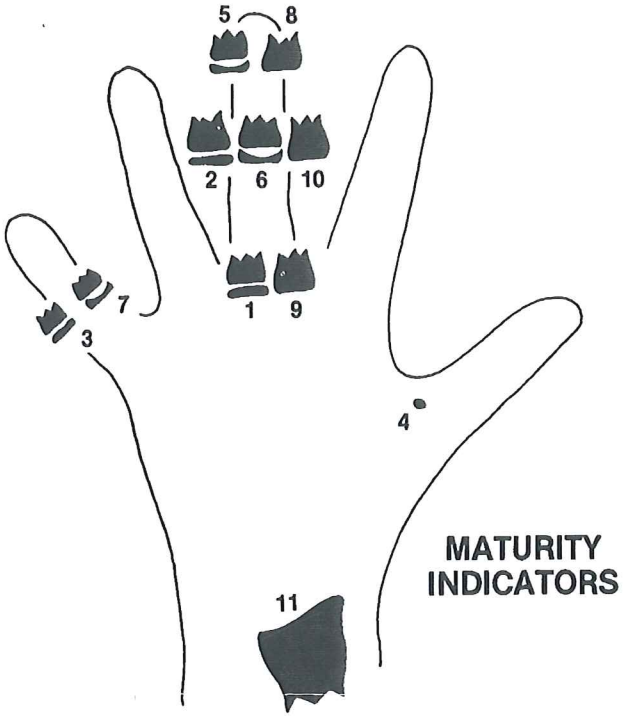
	Male	Female	Total
Study Group	16	9	25

Table 2: Chronological age distribution in study group at T0, T1 and T2

		Mean	Standard Deviation	Minimum	Maximum
Male	**T0**	12 years 2 months	12 months	10 years 9 months	13 years 11 months
	T1	13 years	10 months	11 years 11 months	14 years 6 months
	T2	13 years 6 months	12 months	12 years 2 months	15 years
Female	**T0**	11 years 5 months	7 months	10 years 7 months	12 years 5 months
	T1	12 years 4 months	9 months	11 years 3 months	13 years 7 months
	T2	12 years 9 months	10 months	11 years 7 months	14 years
Total	**T0**	11 years 10 months	10 months	10 years 7months	13 years 11 months
	T1	12 years 9 months	10,5 months	11 years 3 months	14 years 6 months
	T2	13 years 7 months	11 months	11 years 7 months	15 years

Table 3: Growth stage distribution in study group at T0, T1 and T2

		Mean	Standard Deviation	Minimum	Maximum
Male	**T0**	2,31	0,79	1	4
	T1	3,63	1,02	2	6
	T2	4,88	1,5	3	9
Female	**T0**	3,44	0,73	2	4
	T1	5,44	1,33	4	7
	T2	7,33	2,35	5	10
Total	**T0**	2,72	0,84	1	4
	T1	4,28	1,43	2	7
	T2	5,76	2,17	3	10



Fishman

Figure 1: Fishman's 11 skeletal maturity indicator stages.

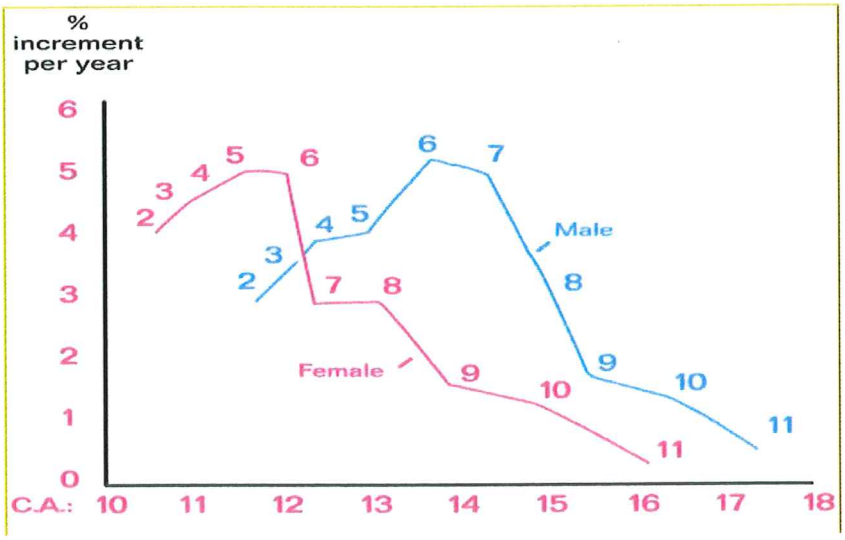


Figure 2: Average statural growth rate for females and males.

5.2. Method

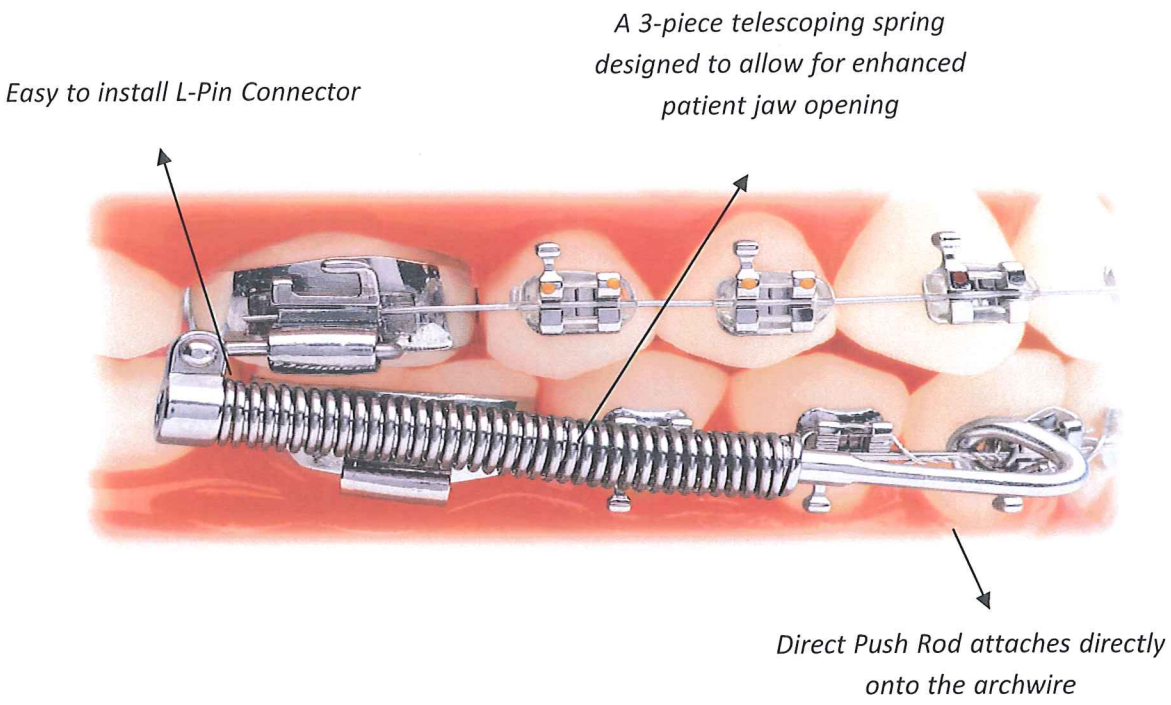
5.2.1. Characteristics of Forsus™ Fatigue Resistant Device

The Forsus™ Fatigue Resistant Device (3M Unitek, Monrovia, California) is an innovative three-piece telescoping spring for Class II correction (Picture 1, 2, 3). It consists of a universal spring module, an 'L' pin and a push rod that is available in four different sizes between 25-35 mm (Picture 4). It is assembled so that the appropriately sized push rod attaches directly to the lower archwire distal to the canine teeth, and the spring to the headgear tube via the 'L' pin. Assembly usually takes a few minutes per side.

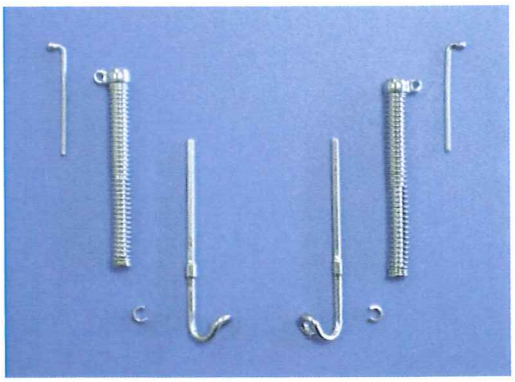
The coaxial spring design of the Forsus™ Fatigue Resistant Device addresses the issue of fatigue failure—a fracture caused by repeated application of stresses in the coil spring. To maximize fatigue life, the Forsus Fatigue Resistant Device is designed to keep these stresses to a minimum.



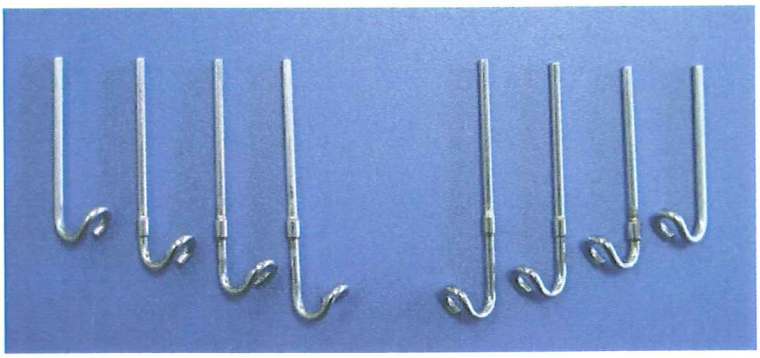
Picture 1: Forsus™ Fatigue Resistant Device L-Pin Module Appliance Kit.



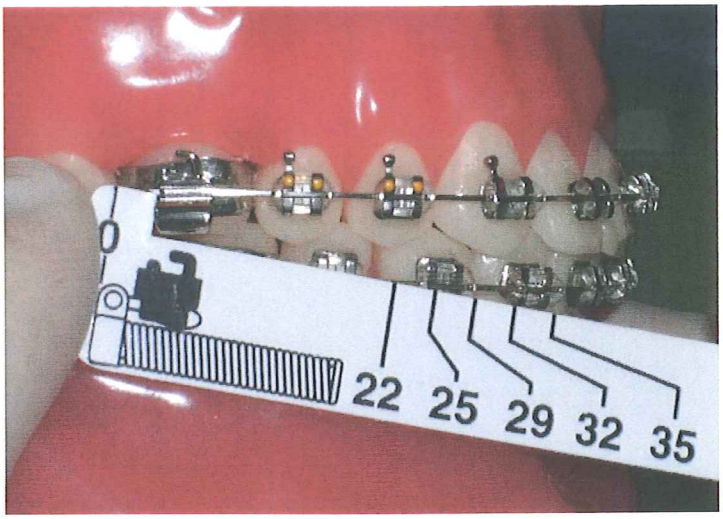
Picture 2: Forsus™ Fatigue Resistant Device L-Pin Module.



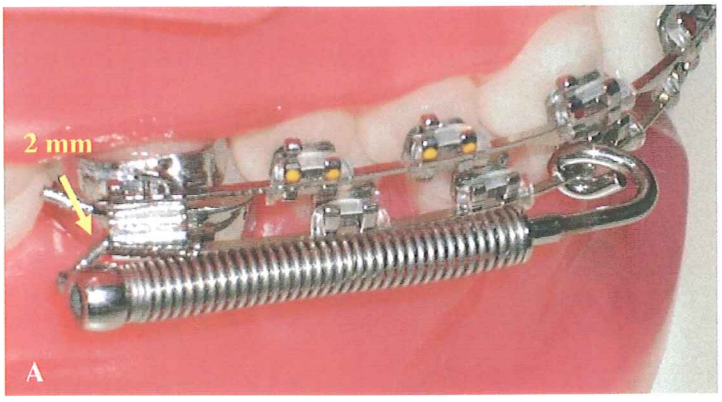
Picture 3: Right and Left Forsus™ Fatigue Resistant Device L-Pin Modules.



Picture 4: Push Rod Kit.

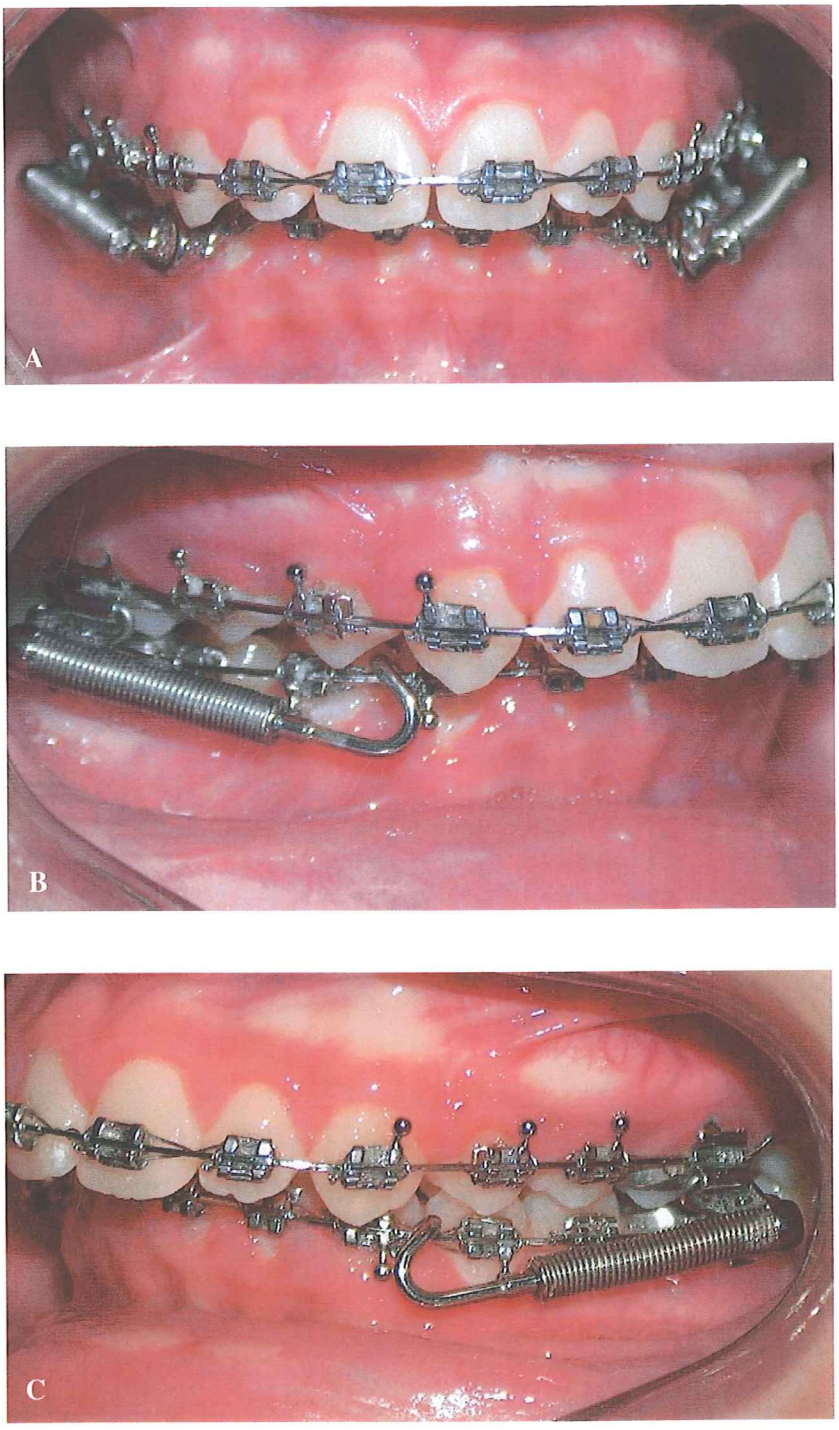


Picture 5: Usage of Forsus™ Device Gauge to choose appropriate push rod size.





Picture 6: L pin is bent occlusally around headgear tube.



Picture 7: Forsus™ Fatigue Resistant Device L-Pin Module in the mouth.

A) Frontal view. **B)** Right side view. **C)** Left side view.

5.2.2. Preparation of the Patients, Application of the Appliance, and Activation/ Reactivation

All of the initial records including intraoral-extraoral photographs (Picture 11, 12), dental casts, lateral cephalograms (Figure 4), panoramic, posterior-anterior and hand-wrist radiographs were taken before the treatment (T0).

After the evaluation of dental casts, if there was any need for expansion, RPE with banded Hyrax was performed (Picture 8) and the appliance was left in the mouth until the end of T2 in order to control upper molar width. 5 out of 25 patients (3 males, 2 females) were applied Hyrax in the study. A 1.0 mm stainless steel transpalatal arch (TPA) was attached on the first molar bands (Picture 9) in the beginning to the rest of the patients for the same reason. If there was any molar rotation it was also corrected by activating TPA before the leveling and alignment phase. Additionally, a 1.0 mm lingual arch was placed to the lower jaw (Picture 10) in all patients in order to maintain lower arch perimeter.

Alignment and leveling procedures started in every patient with a 0.018 slot Roth Prescription. Upper bands with triple and lower bands with double attachments were used. Wire sequence progressed up to a 0,017 x 0,025 stainless steel archwire on the upper and lower arches. Both archwires were cinched back and the lower teeth were laced between the first bicuspids to prevent space opening.

At this time point (Picture 13, 14); a new lateral cephalogram (Figure 5) and hand-wrist radiograph were taken (T1). Average treatment time between T0-T1 was 10 months 12 days ± 3 months 25 days.

Patients at this visit had the Forsus™ Fatigue Resistant Device (FRD) delivered (Picture 15).

While inserting spring module, "L" ball pin was inserted into spring module distal-end pin hole and was pulled through headgear tube from distal to mesial. "L" ball pin was bent around headgear tube occlusally (Picture 6). 1 to 2 mm clearance between distal end of tube and pin ball was left to allow for pin adjustments and avoid restricted movement (Picture 6A).

After the installation of spring module, it is important to choose appropriate push rod size. The distance between distal end of upper molar tube to distal end of lower cuspid bracket while in centric occlusion was measured with the use of Forsus™ Device Gauge and the appropriate size was fixed (Picture 5). Push rod was inserted into the spring and loop was placed between cuspid and first bicuspid. The push rod was crimped mesial end by closing loop around archwire.

After the delivery, patients were seen in monthly evaluation visits. At the first visit no activation was done. At the second visit activation was performed by crimping one split ring bushing on push rod distal of stopper by compressing the spring as needed. If activation was needed, no other split ring bushing was put; the push rod was changed with one size larger rod. At the other visits when Class I relation was achieved no activation was performed and the device was kept in the mouth for one more month for overcorrection. After achieving Class I or Super Class I molar and canine relation the device was removed (Picture 17, 18).

A new lateral cephalogram (Figure 7) and hand-wrist radiograph were taken just after the appliance removal (T2). Patients maintained the FRD for an average 6 months 2 days ± 2 months 16 days (T1-T2).

The TPA -or if there is hyrax- and lingual arch were also removed to facilitate settling of the occlusion. The patients were instructed to wear intermaxillary Class II elastics for a few month periods in order to maintain the Class II correction and allow a proper interdigitation of the posterior occlusion.

Treatment changes between T0 and T1 were accepted as control values and were compared with the changes between T1 and T2.

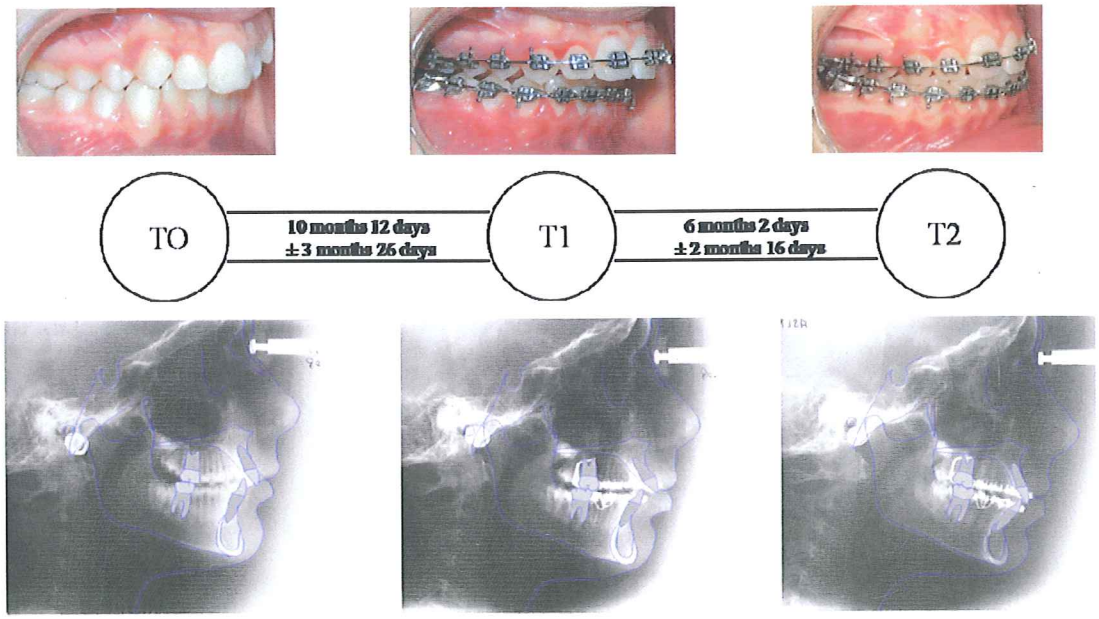
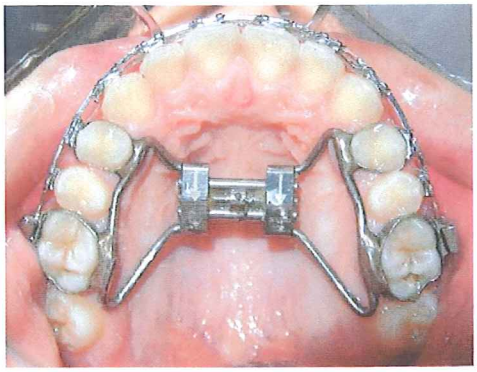


Figure 3: Stages of the study.



Picture 8: Occlusal view of the upper arch with Banded Hyrax.



Picture 9: Occlusal view of the upper arch with transpalatal arch.



Picture 10: Occlusal view of the lower arch with lingual arch.



Picture 11: Extraoral photographs of the patient at T0.



Picture 12: Intraoral photographs of the patient at T0.

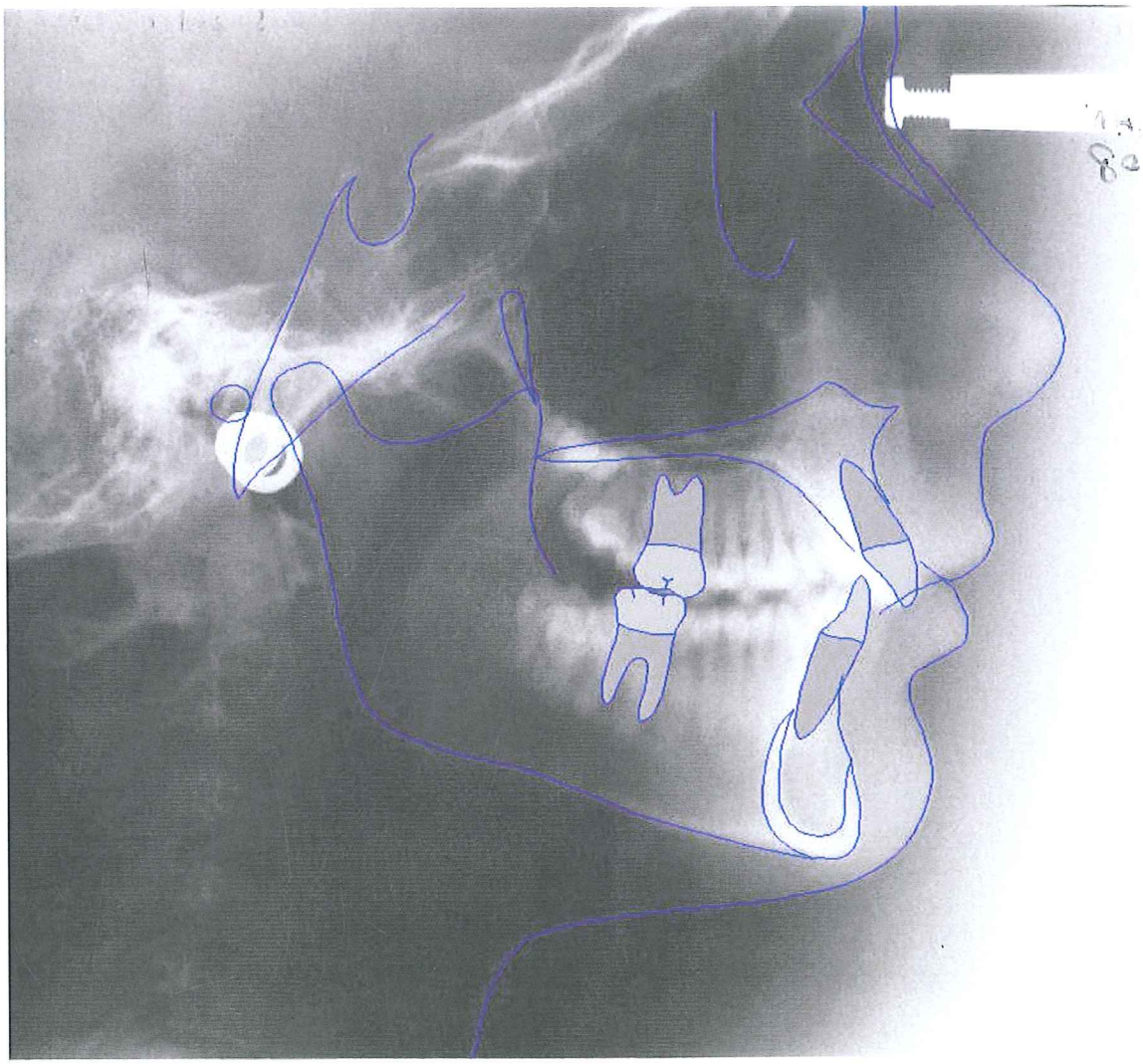
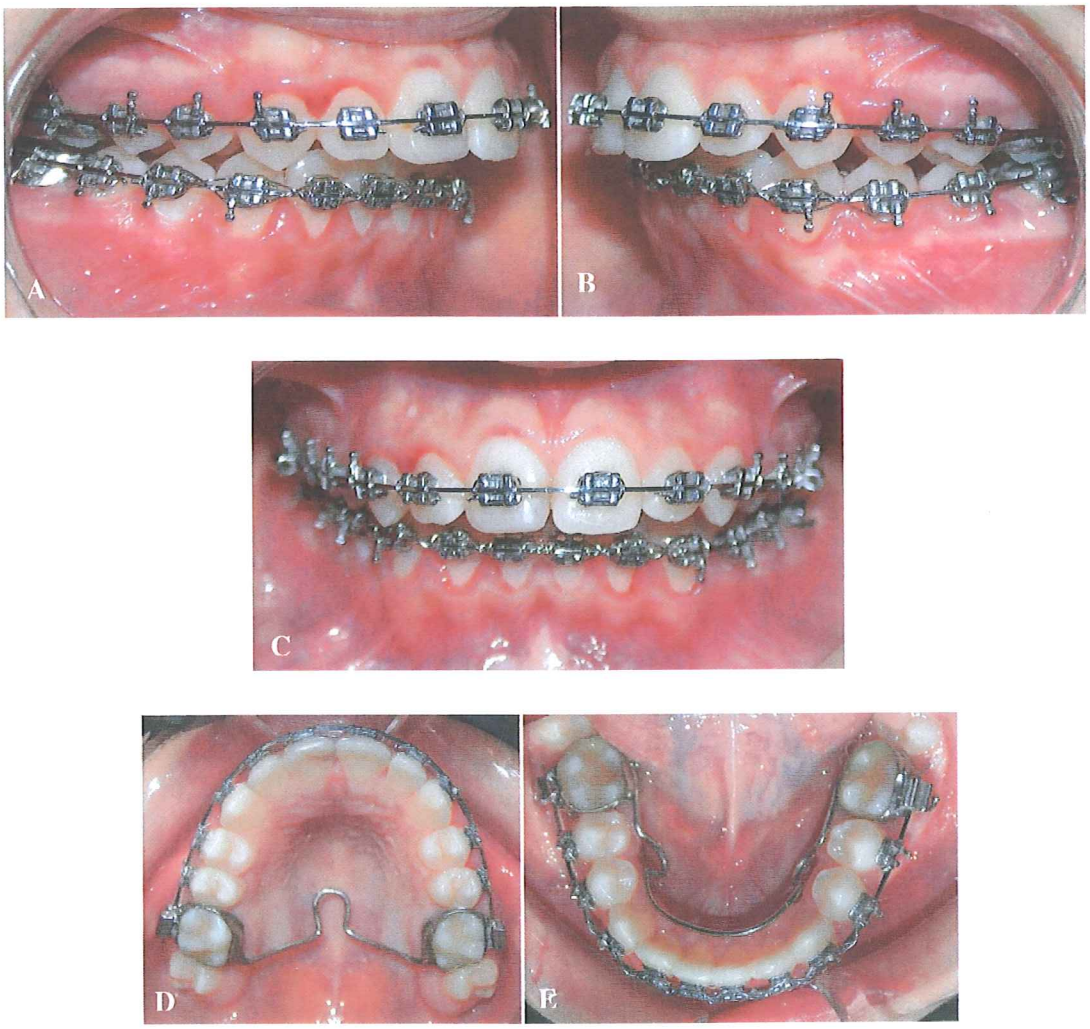


Figure 4: Lateral cephalometric radiogram of the patient at T0.



Picture 13: Extraoral photographs of the patient at T1.



Picture 14: Intraoral photographs of the patient at T1.

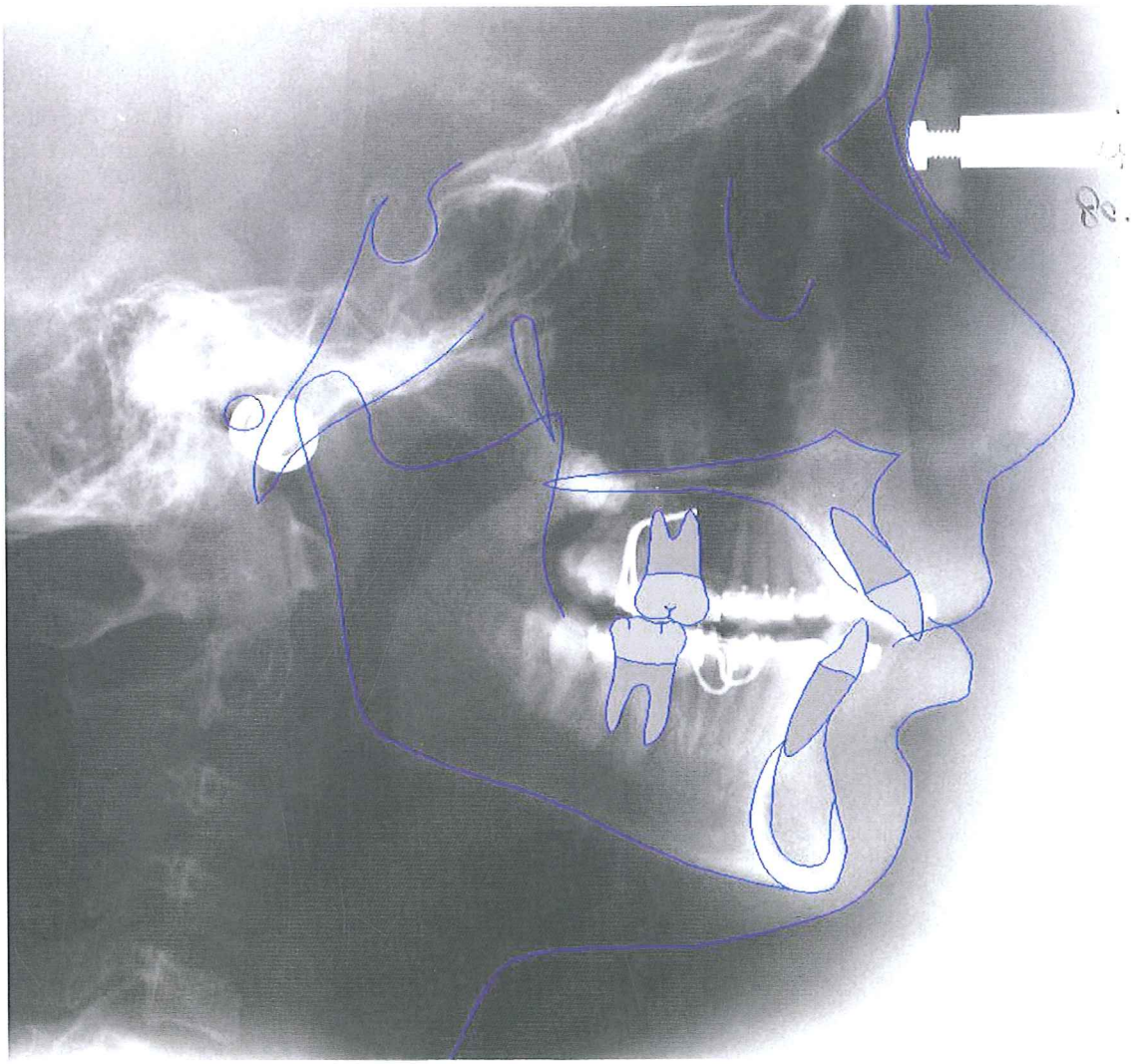


Figure 5: Lateral cephalometric radiogram of the patient at T1.

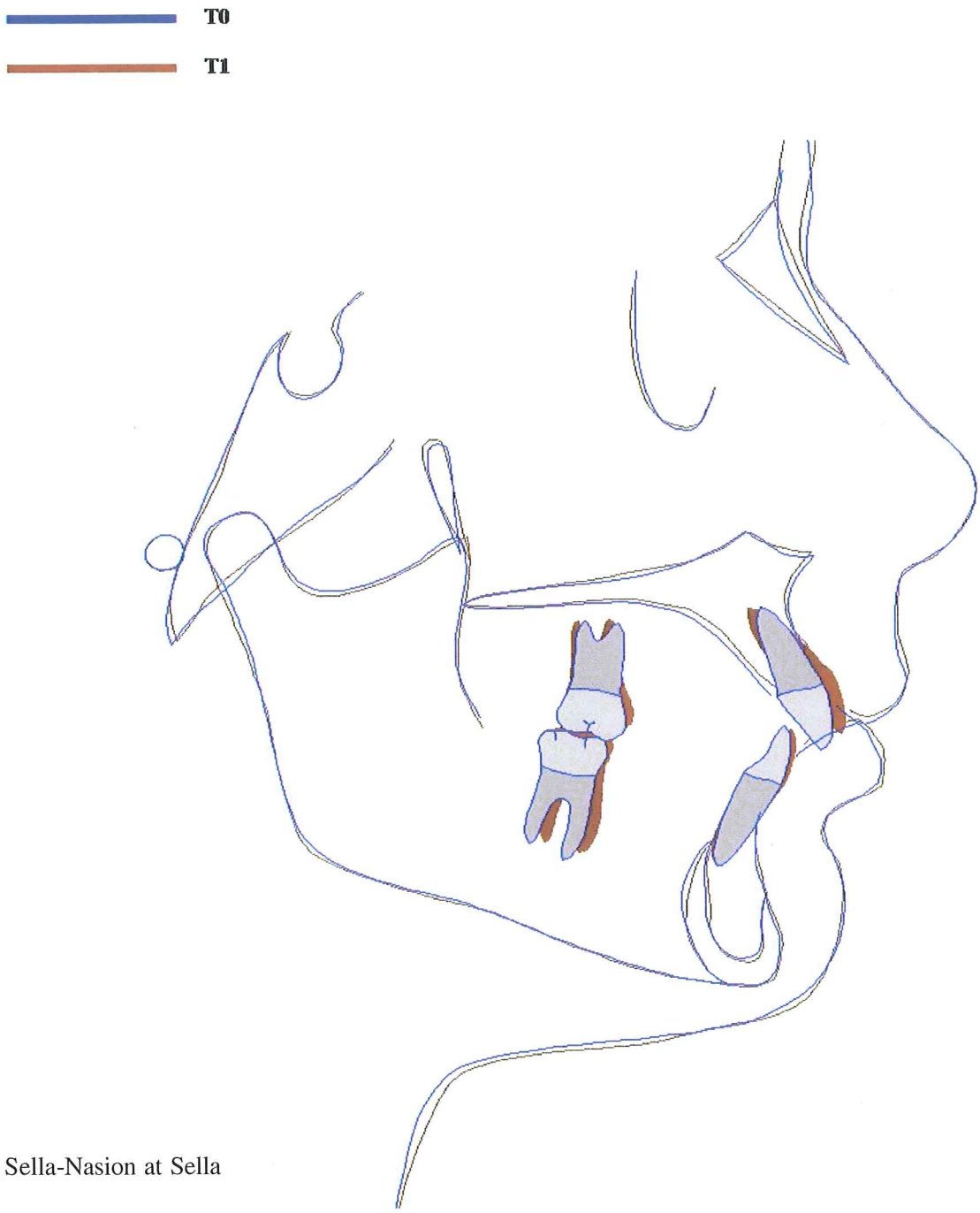
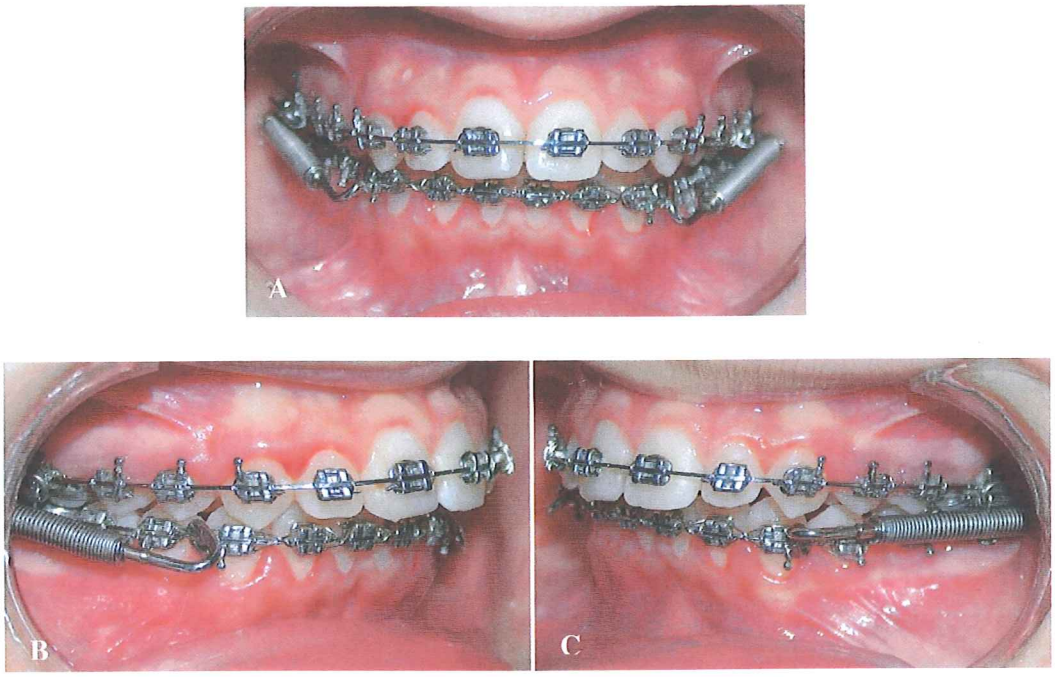


Figure 6: Superimposition of the lateral cephalometric radiograms taken at T0 and T1.

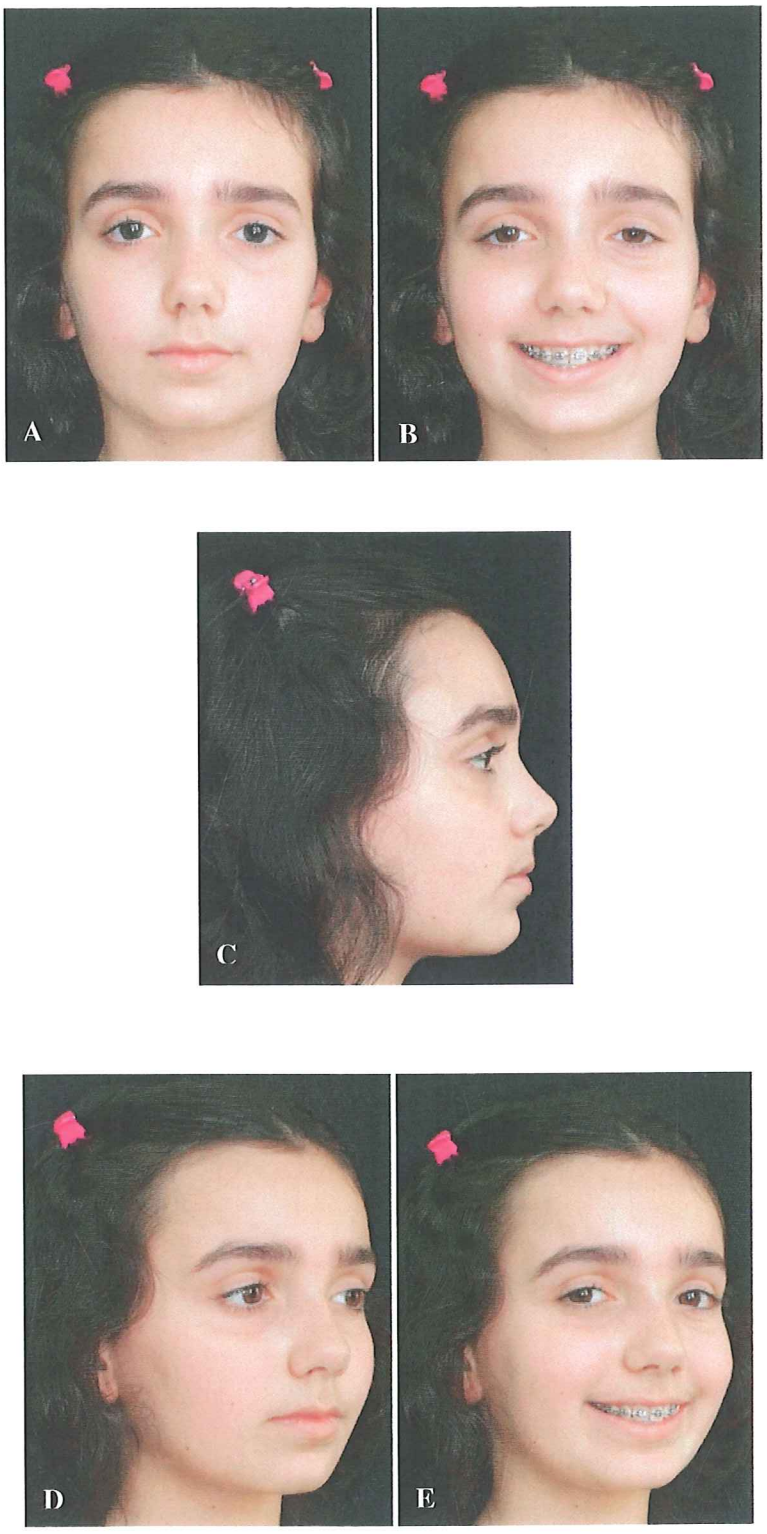


Picture 15: Forsus™ Fatigue Resistant Device L-Pin Module in the mouth.

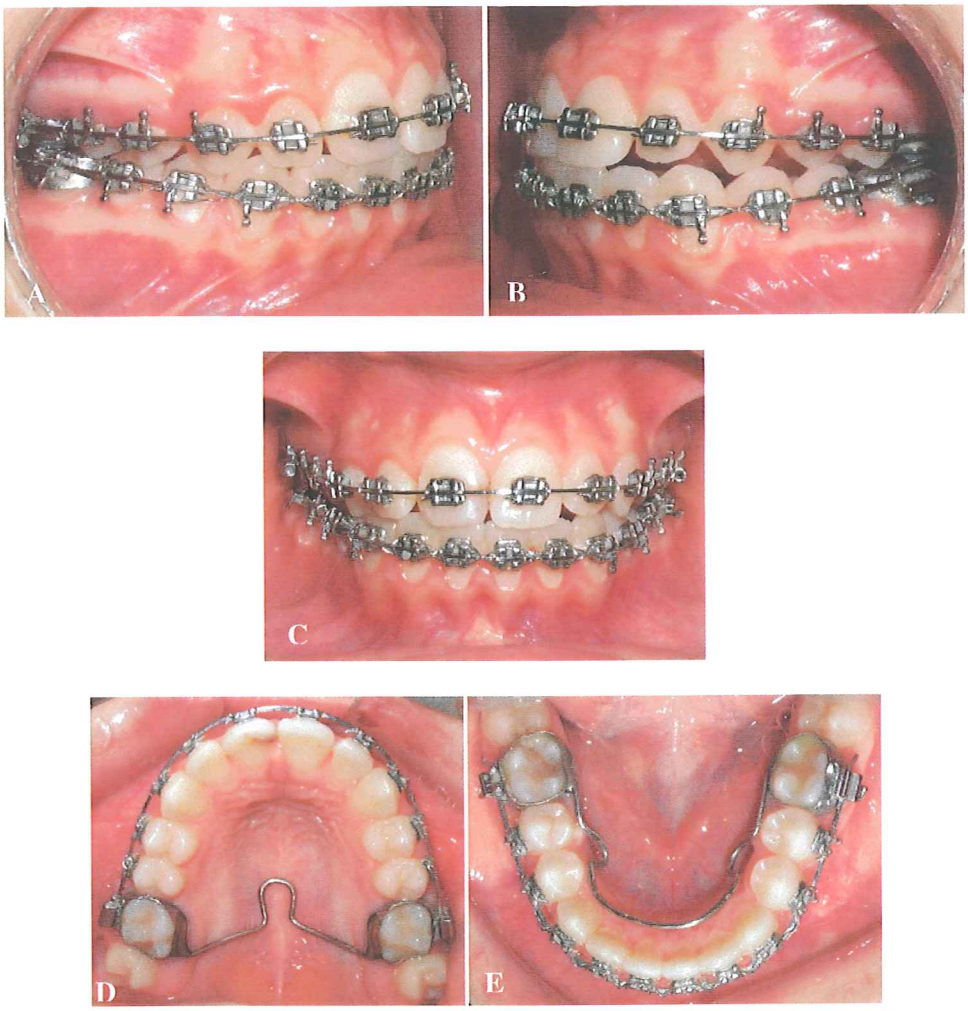
A) Frontal view. **B**) Right side view. **C**) Left side view.



Picture 16: Amount of OJ at T1.



Picture 17: Extraoral photographs of the patient at T2.



Picture 18: Intraoral photographs of the patient at T2.

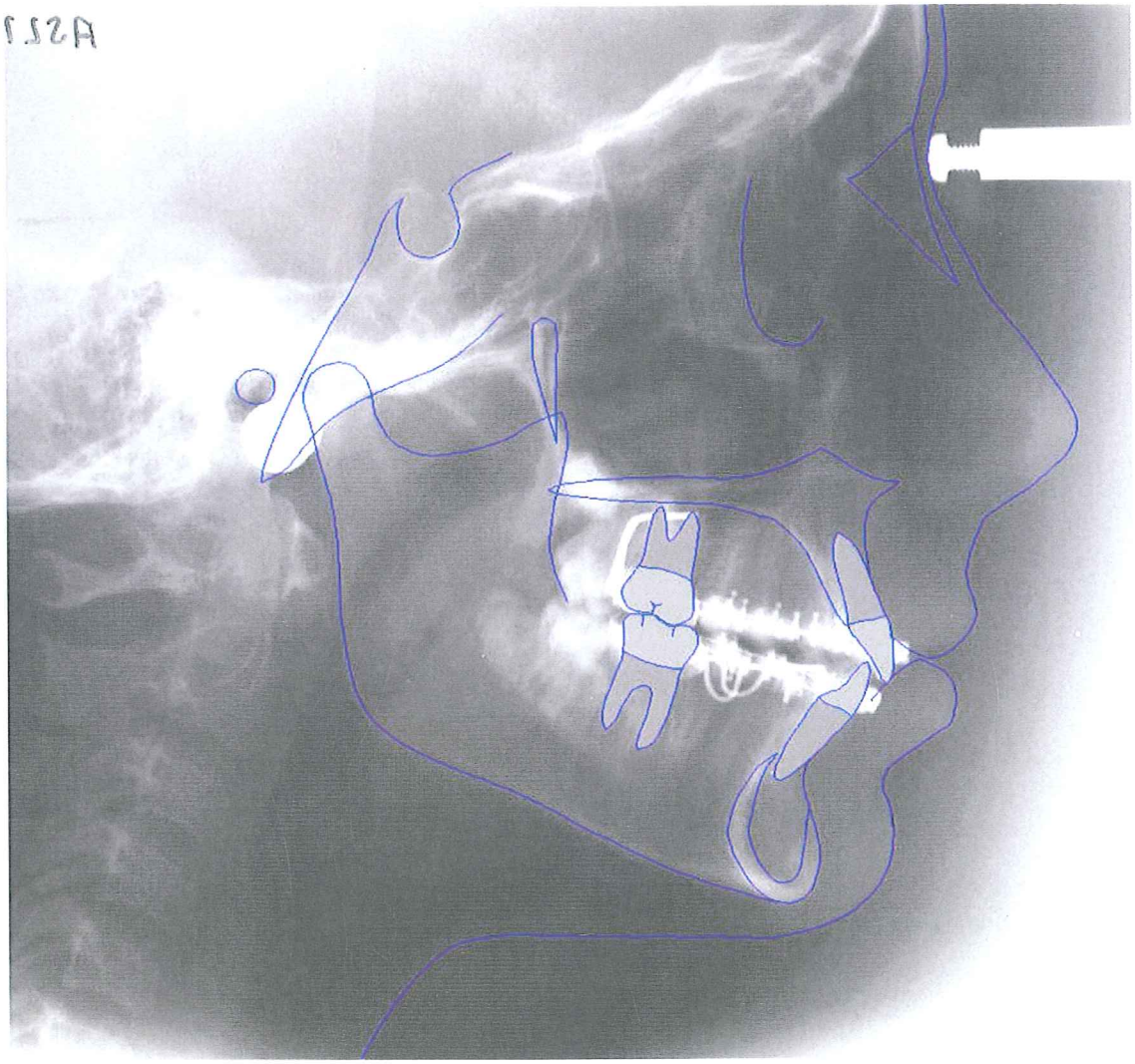


Figure 7: Lateral cephalometric radiogram of the patient at T2.

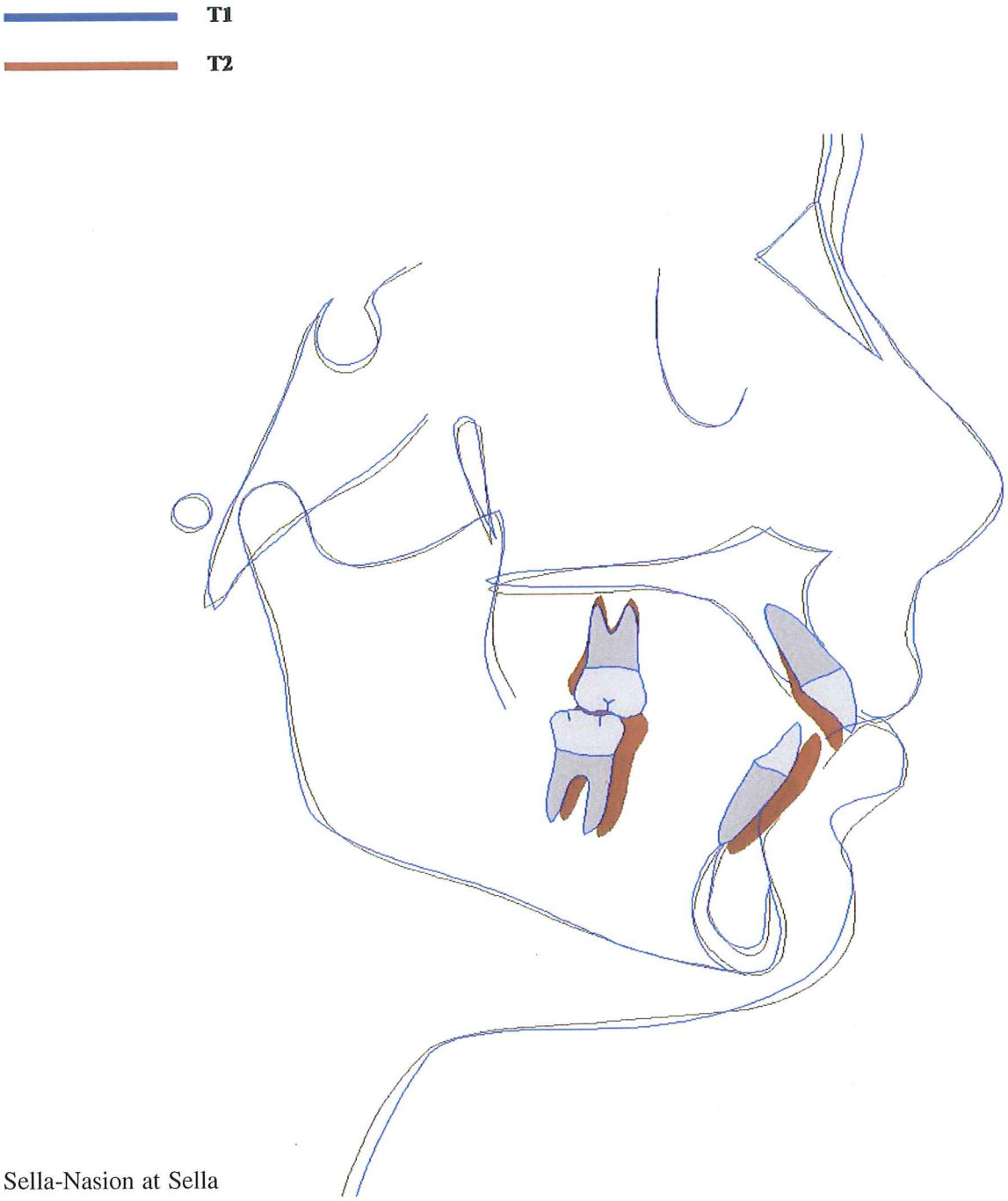
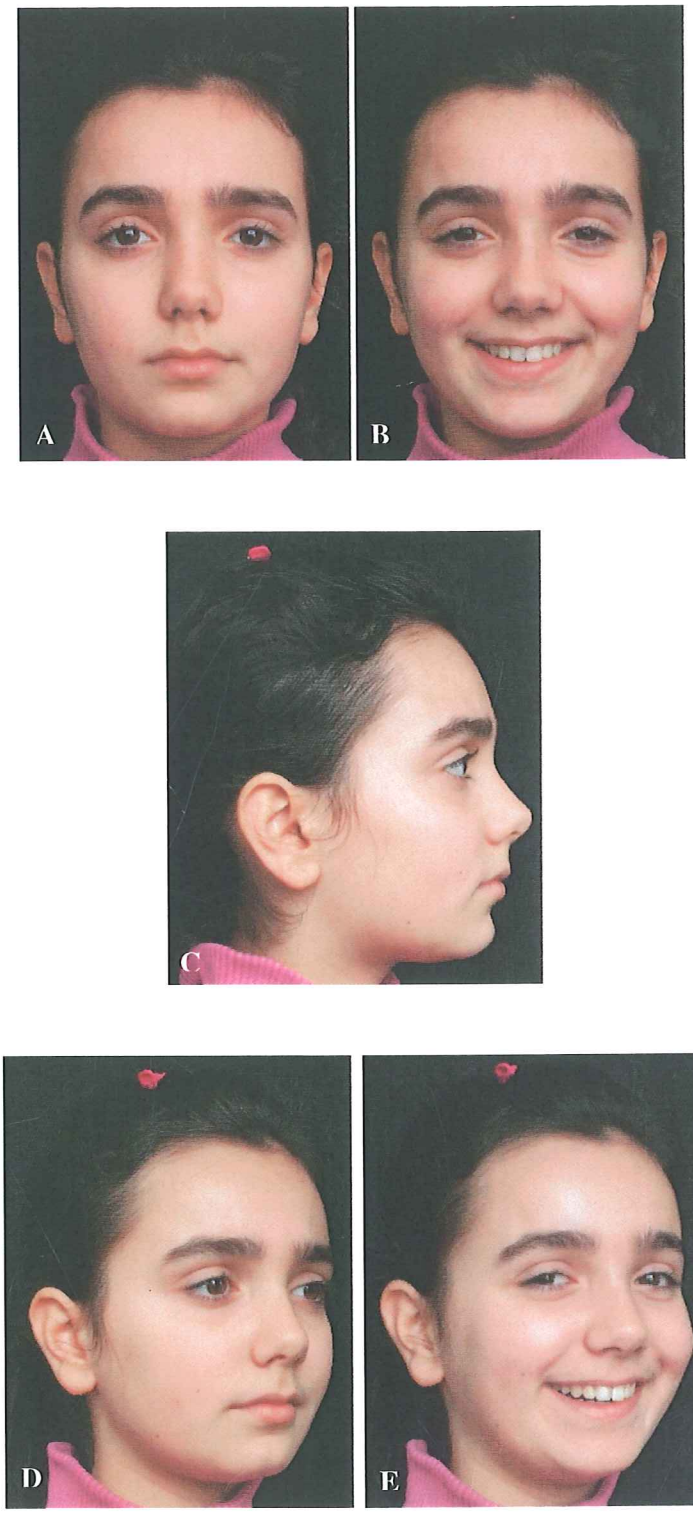


Figure 8: Superimposition of the lateral cephalometric radiograms taken at T1 and T2.



Picture 19: Extraoral photographs of the patient at T3.



Picture 20: Intraoral photographs of the patient at T3.

5.2.3. Patient Consent

All of the patients were informed about the study and consent forms were signed by the parents. Oral hygiene training was given at the start of the treatment. Before the installation of FRD they were also informed about some difficulties including:

- Difficulties in jaw movement,
- Spring module can occasionally become disengaged from the molar tube,
- Spring module and push rod can become disengaged with a wide mouth opening (The patients were taught how to reinsert these parts),
- Tissue irritations at the corners of the mouth and in the buccal corridor distal to the maxillary molar can be observed (Often this corresponds to the patient sleeping on the irritated site. To help alleviate this problem, the patient is instructed not to sleep on cheek),
- Breakage of some brackets –especially lower canine brackets-.

They were instructed to inform us in any extraordinary situation. If there is a disengagement and breakage it was fixed immediately. If there is a big tissue irritation, the appliance were removed and waited for healing, and inserted again. 0,2 % Klorhexidin Glukonat (Oroheks, Abdi İbrahim İlaç San. ve Tic. A.Ş Hadımköy/İstanbul) were advised to use besides routine oral hygiene rules in case of tissue irritation.

Patients were also informed about difficulties in speech which may be derived from TPA, lingual arch, hyrax or FRD at the start of the treatment. These difficulties usually disappeared in a few weeks.

5.2.4. Cephalometric Evaluation

All of the cephalometric radiographs were taken by the same machine in Department of Oral Diagnosis and Radiology, Faculty of Dentistry, University of Marmara. Morita Veraviewapocs machine and Starlight© X-Ray film cassettes were used to take radiographs. The distance between the x-ray source and subjects' ortho-

axial plane was 180 cm and the distance between the x-ray film and subjects' ortho-axial plane was 12 cm and the subjects were posed for 1,2 seconds for lateral cephalograms. All of the films were developed in Kodak Medical X-Ray Processor machine.

Lateral cephalograms were hand-traced by the same observer on acetate paper by a 0,3-mm lead pencil, and double images were centered while tracing. In order to reduce the method error, three cephalograms of one patient were traced in the same day.

For some of the linear measurements on cephalograms taken at T0, T1 and T2, the horizontal reference line (RL1) and the vertical reference line (RL2) from the first film were used as a reference grid for the sagittal registrations. The grid was transferred from the first roentgenogram to the following roentgenograms in a series by superimposition of the roentgenograms on the SN line with sella (S) as the registration point.

In this study, 25 cephalometric landmarks and 43 cephalometric measurements were used.

5.2.4.1. Landmarks Used in Lateral Cephalometric Analysis (Figure 9)

1- (S): Sella; the centre of hypophyseal fossa (sella turcica).

2- (N): Nasion; the fronto-nasal suture at its most superior point on the curve at the bridge of the nose.

3- (ANS): Anterior nasal spine; the most anterior point on the maxilla at the level of the plate.

4- (PNS): Posterior nasal spine; the most posterior point on the bony hard plate in the sagittal plane.

5- (A): A point; subspinale; the most posterior point of the curve between ANS and supradentale.

6- (B): B point; supramentale; the most posterior point of the bony curvature of the mandible below infradentale and above pogonion.

7- (Go): Gonion; the most posterior inferior point at the angle of the mandible.

8- (Me): Menton; the lowest point on the symphyseal outline of the chin.

9- (Pg): Pogonion; the most anterior point on the symphyseal outline of the chin.

10- (Gn): Gnathion; a point located by taking the midpoint between the most anterior (Pg) and inferior (Me) points of the bony chin.

11- (Ar): Articulare; a point at the junction of the posterior border of the ramus and the inferior border of the posterior cranial base (occipital bone).

12- (U1): Upper incisor tip; the incisal tip of the most anterior maxillary central incisor.

13- (L1): Lower incisor tip; the incisal tip of the most anterior mandibular central incisor.

14- (U1a): Upper incisor root apex.

15- (L1a): Lower incisor root apex.

16- (U6): Mesiobuccal cusp tip of maxillary first molar.

17- (L6): Mesiobuccal cusp tip of mandibular first molar.

18- (L): Perpendicular projection of Pogonion on SN line.

19- (E): Perpendicular projection of Articulare on SN line.

20- (N'): Soft-tissue nasion; point at which an extension of the nasion-sella line (NSL) meets the soft-tissue profile of the nose.

21- (No): Nose tip; the most anterior point on the soft-tissue profile of the nose determined by a tangent perpendicular to the sella-nasion line (SN).

22- (Sn): Subnasale; the point at which the columella (nasal septum) merges with the upper lip in the midsagittal plane.

23- (Ls): Labiale superior; the most anterior point on the maxillary lip.

24- (Li): Labiale inferior; the most anterior point on the mandibular lip.

25- (Pg'): Soft-tissue pogonion; the most anterior point of the soft-tissue profile of the chin determined by a tangent perpendicular to the mandibular plane (MP).

5.2.4.2. Planes Used in Lateral Cephalometric Analysis (Figure 10)

1- SN: Sella-Nasion plane; line passing through S and N points.

2- PP: Palatal plane; line passing through ANS and PNS points.

3- OP: Occlusal plane; line bisecting the cusp tips of the molars and passing through the cusp tips of the first premolars.

4- MP: Mandibular plane; line passing through Go and Me points.

5- E Line: Line connecting the tip of nose and the most anterior point of the soft-tissue pogonion.

6- Upper incisor axis: (U1); line passing through incisal tip and root apex of the upper central incisor.

7- Lower incisor axis: (L1); line passing through incisal tip and root apex of the lower central incisor.

5.2.4.3. Reference Lines (Figure 11)

1-Horizontal reference line: (RL1); constructed Frankfort horizontal plane; an artificial horizontal reference plane starting from S point, displaying 7° angle under SN plane.

2- Vertical reference line: (RL2); an artificial reference plane drawn perpendicular to horizontal reference plane from S point.

5.2.4.4. Skeletal Measurements Used in Lateral Cephalometric Analysis

5.2.4.4.1. Angular Skeletal Measurements Used in Lateral Cephalometric Analysis (Figure 12)

1- SNA: Antero-posterior position of maxilla to cranial base.

2- SNB: Antero-posterior position of mandible to cranial base.

3- ANB: Antero-posterior relationship between maxilla and mandible.

4- SN-MP: Cranial base to mandibular plane angle.

5- SN-PP: Cranial base to palatal plane angle.

6- PP-MP: Palatal plane to mandibular plane angle.

7- Gonial Ratio: Ratio between the posterior and anterior angles of the gonial angle when divided by a line passing through the Gonion and the Nasion.

5.2.4.4.2. Linear Skeletal Measurements Used in Lateral Cephalometric Analysis (Figure 13)

1- ANS-Me: Lower face height perpendicular to RL1.

2- N-Me: Anterior face height perpendicular to RL1.

3- ANSMe / NMe: Ratio between lower face height and anterior face height.

4- S-Go: Posterior face height.

5- Jarabak: S-Go / NMe; ratio between posterior face height and anterior face height.

6- SL: Distance between sella and L point.

7- SE: Distance between sella and E point.

8- Ar-Go: Distance between articulare and Gonion.

9- Go-Gn: Distance between gonion and Gnathion.

10- Ar-Pg: Distance between articulare and Pogonion.

11- Pg-RL2: Distance from pogonion to vertical reference line perpendicular to vertical reference line.

12- Ar-RL2: Distance from articulare to vertical reference line perpendicular to vertical reference line.

13- Mandibular length: Sum of Pg-RL2 and Ar-RL2.

14- A-RL2: Distance from A point to vertical reference line perpendicular to vertical reference line.

15- A-RL1: Distance from A point to horizontal reference line perpendicular to horizontal reference line.

5.2.4.5. Dental Measurements Used in Lateral Cephalometric Analysis

5.2.4.5.1. Angular Dental Measurements Used in Lateral Cephalometric Analysis (Figure 14)

1- SN/OP: Cranial base to occlusal plane angle.

2- U1/SN: Angle of maxillary incisor to cranial base.

3- IMPA: Angle of mandibular incisor to mandibular plane.

5.2.4.5.2. Linear Dental Measurements Used in Lateral Cephalometric Analysis (Figure 15)

1- OB: Overbite; the vertical distance between upper and lower incisor tips' projection perpendicular to horizontal reference line.

2- OJ: Overjet; the horizontal distance between upper and lower incisor tips' projection perpendicular to vertical reference line.

3- U1- RL2: Distance from upper central incisor edge to vertical reference line perpendicular to vertical reference line.

4- U1-RL1: Distance from upper central incisor edge to horizontal reference line perpendicular to horizontal reference line.

5- L1-RL2: Distance from lower central incisor edge to vertical reference line perpendicular to vertical reference line.

6- L1-RL1: Distance from lower central incisor edge to horizontal reference line perpendicular to horizontal reference line.

7- U6-RL2: Distance from mesial cusp tip of the maxillary first molar to vertical reference line perpendicular to vertical reference line.

8- U6-RL1: Distance from mesial cusp tip of the maxillary first molar to horizontal reference line perpendicular to horizontal reference line.

9- L6-RL2: Distance from mesial cusp tip of the mandibular first molar to vertical reference line perpendicular to vertical reference line.

10- L6-RL1: Distance from mesial cusp tip of the mandibular first molar to horizontal reference line perpendicular to horizontal reference line.

11- Holdaway: Ratio between the prominence of the mandibular incisor tip to NB line and the Pogonion to NB line.

5.2.4.6. Soft-tissue Measurements Used in Lateral Cephalometric Analysis

5.2.4.6.1. Angular Soft-tissue Measurements Used in Lateral Cephalometric Analysis (Figure 16)

1- NLA: Naso-labial angle; angle between the tangent to the columella of the nose and the upper lip line formed between points Subnasale and Labiale superius.

2- N'-Sn'-Pg': Soft-tissue profile angle; angle of soft-tissue facial convexity excluding the nose, formed by points soft-tissue Nasion, Subnasale and soft-tissue Pogonion.

5.4.6.2. Linear Soft-tissue Measurements Used in Lateral Cephalometric Analysis (Figure 17)

1- Labiale superior-RL2: Distance from labialis superior to vertical reference line perpendicular to vertical reference line.

2- Labiale inferior-RL2: Distance from labialis inferior to vertical reference line perpendicular to vertical reference line.

3- Labiale superior-E Line: Distance from labialis superior to E line perpendicular to E line.

4- Labiale inferior-E Line: Distance from labialis inferior to E line perpendicular to E line.

5- Pg'-RL2: Distance from soft-tissue pogonion to vertical reference line perpendicular to vertical reference line.

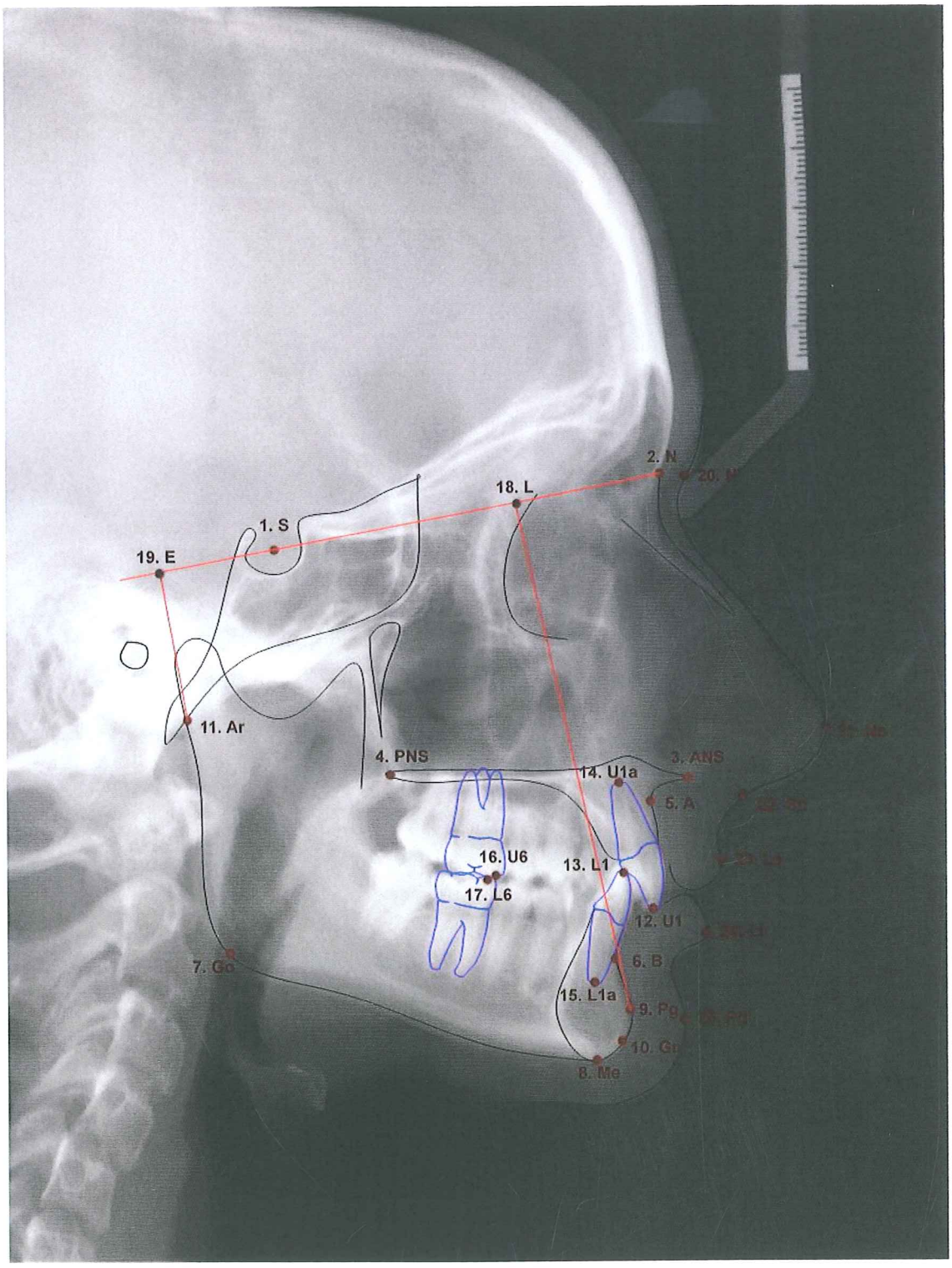


Figure 9: Landmarks used in lateral cephalometric analysis.

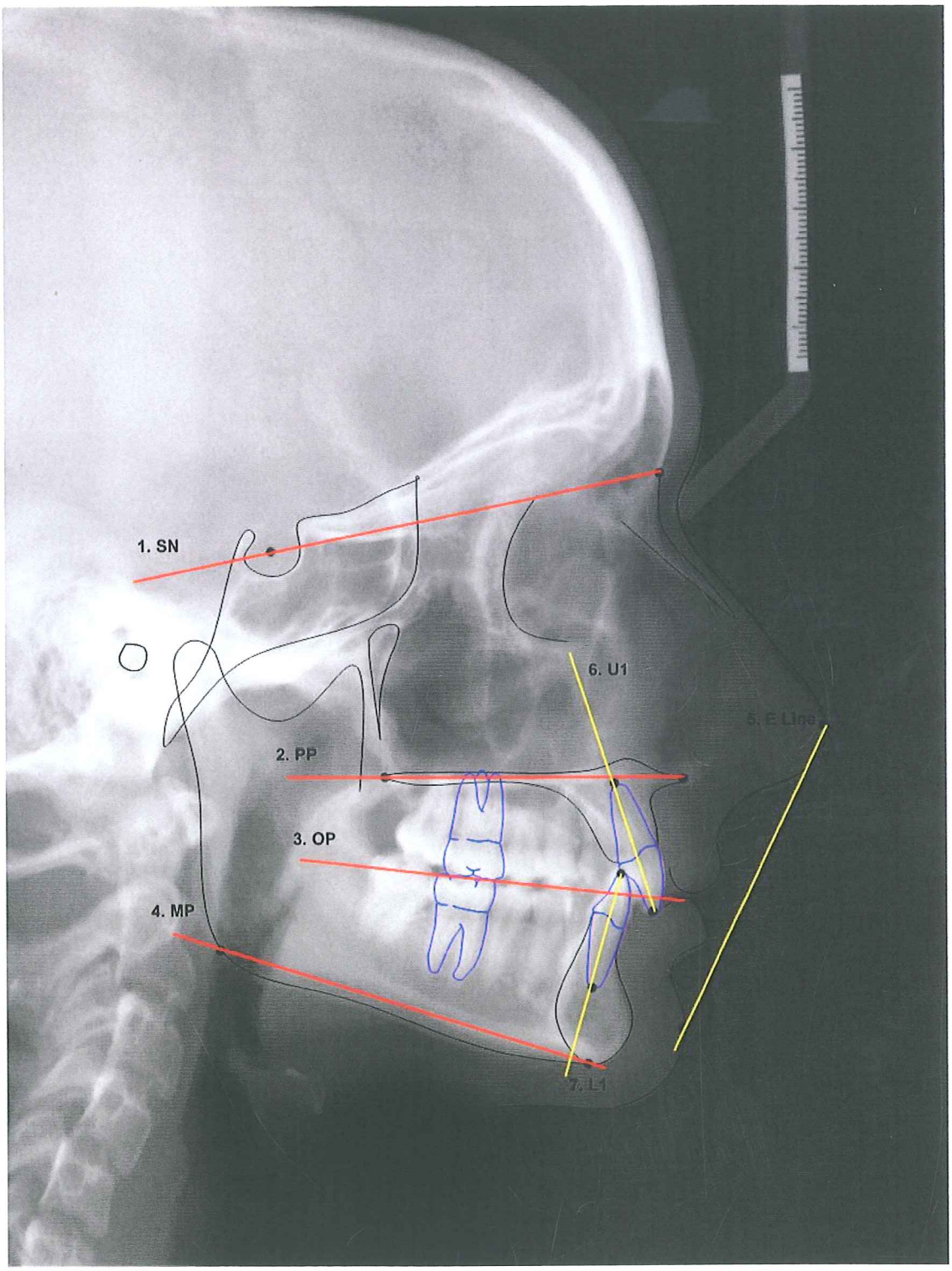


Figure 10: Planes used in lateral cephalometric analysis.

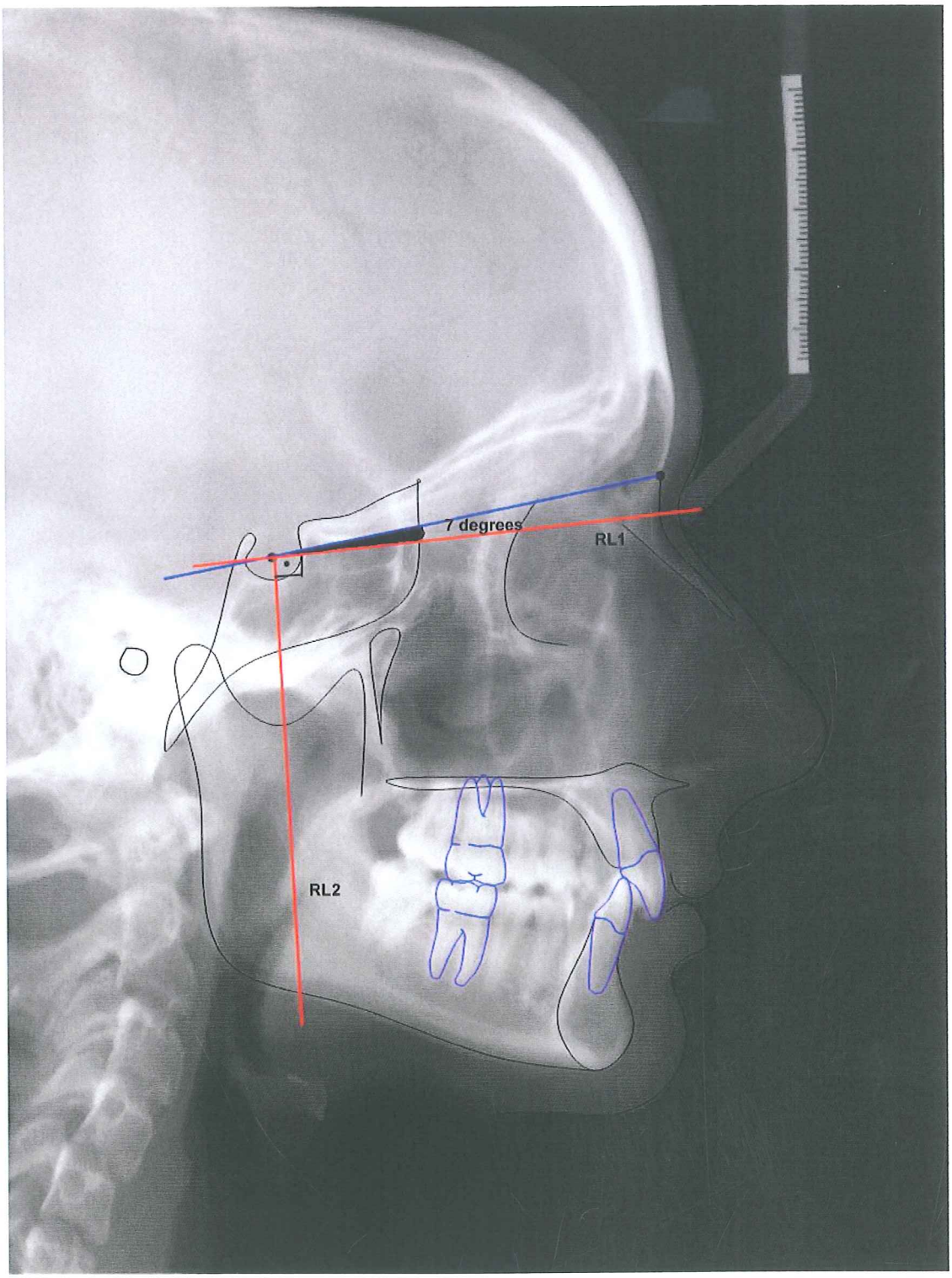


Figure 11: Reference lines used in lateral cephalometric analysis.

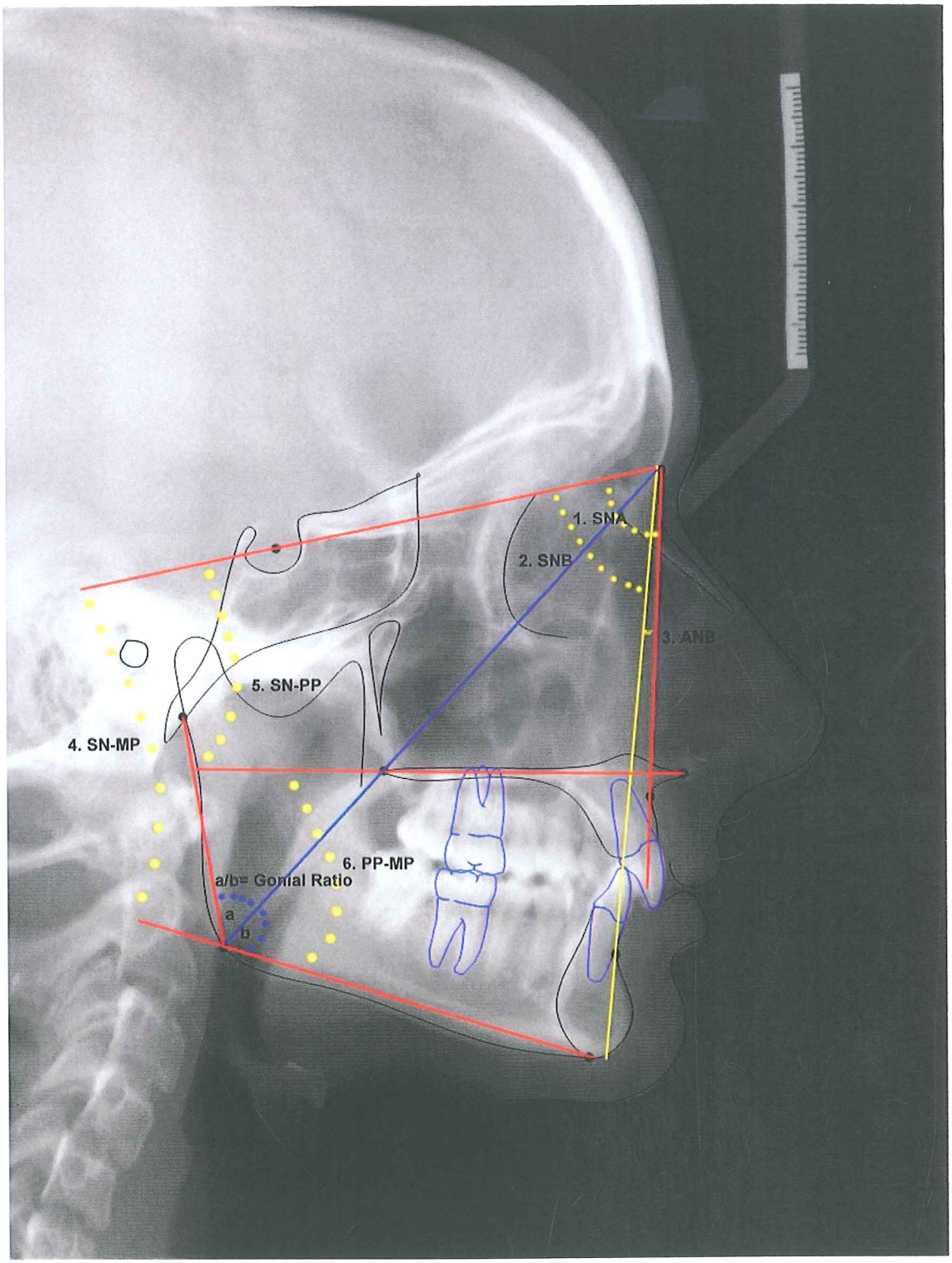


Figure 12: Angular skeletal measurements used in lateral cephalometric analysis.

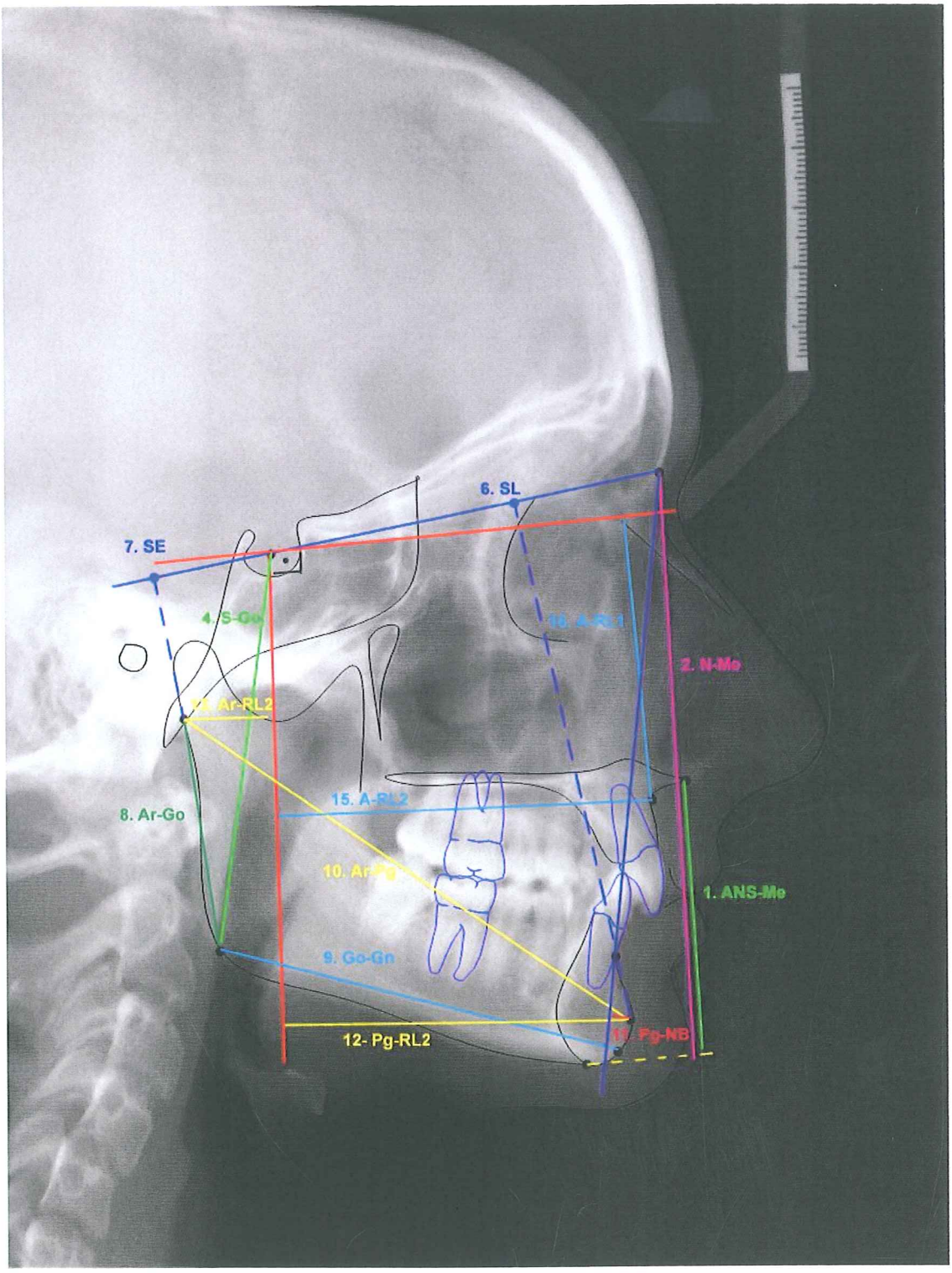


Figure 13: Linear skeletal measurements used in lateral cephalometric analysis.

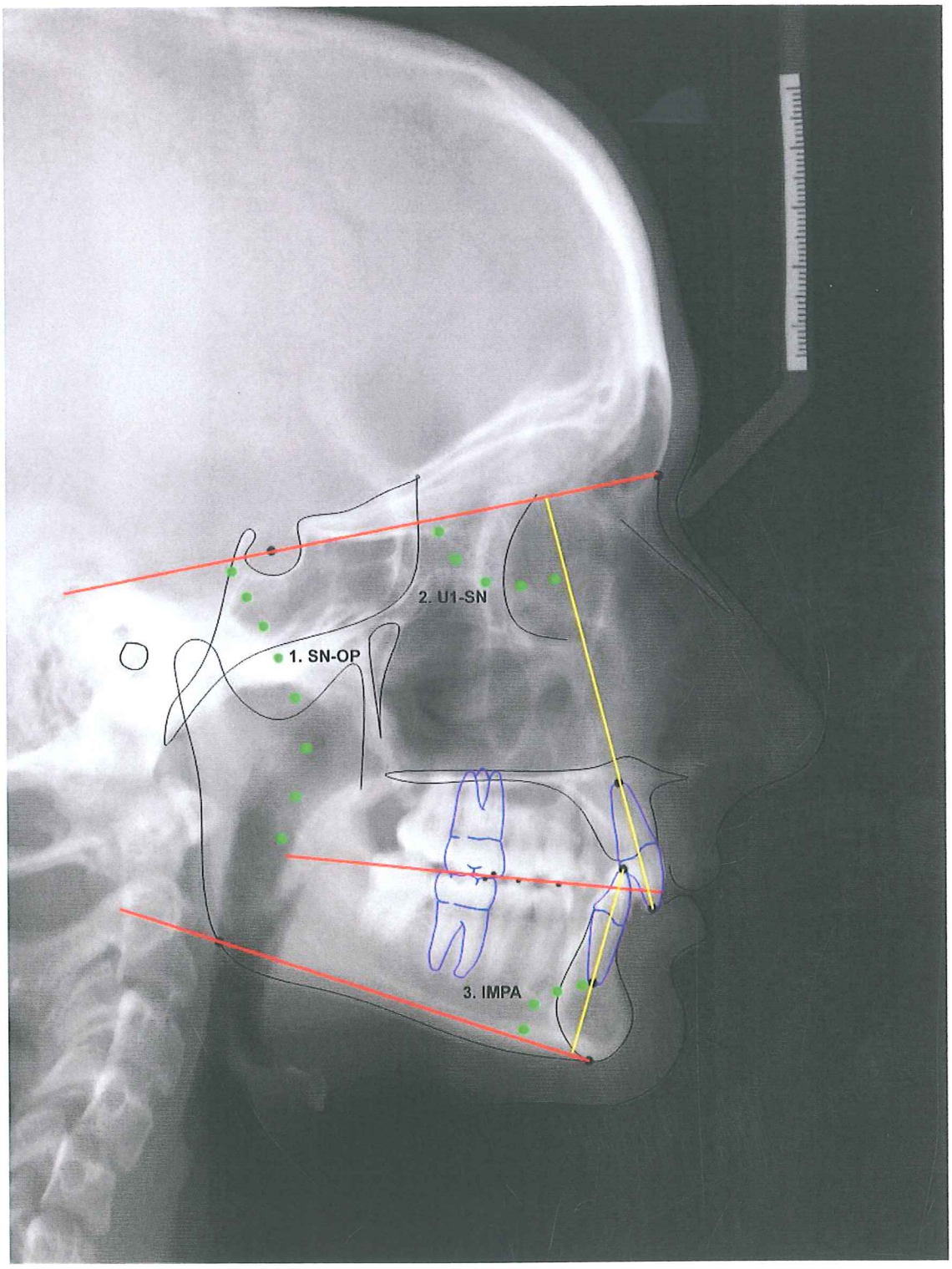


Figure 14: Angular dental measurements used in lateral cephalometric analysis.

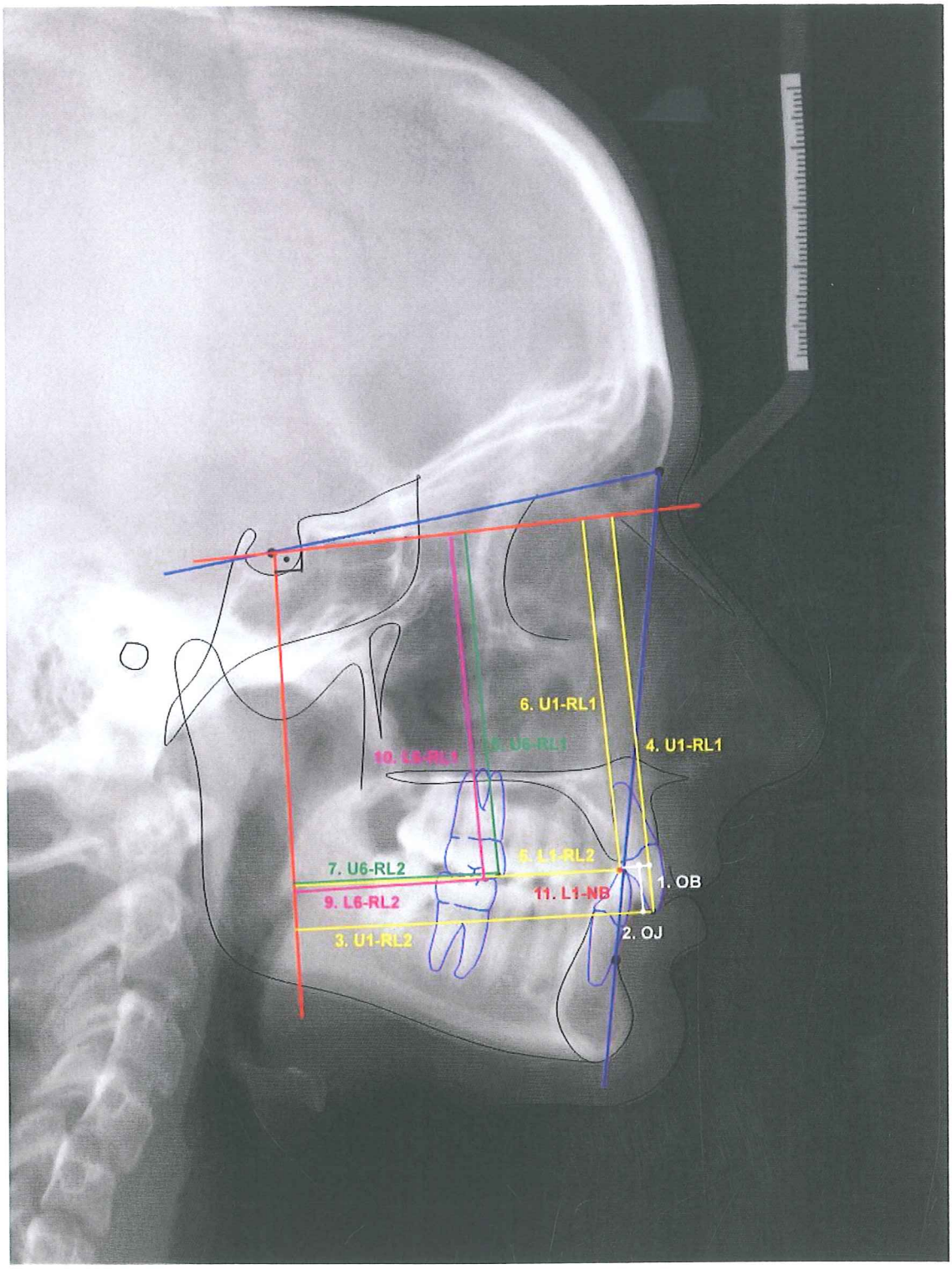


Figure 15: Linear dental measurements used in lateral cephalometric analysis.

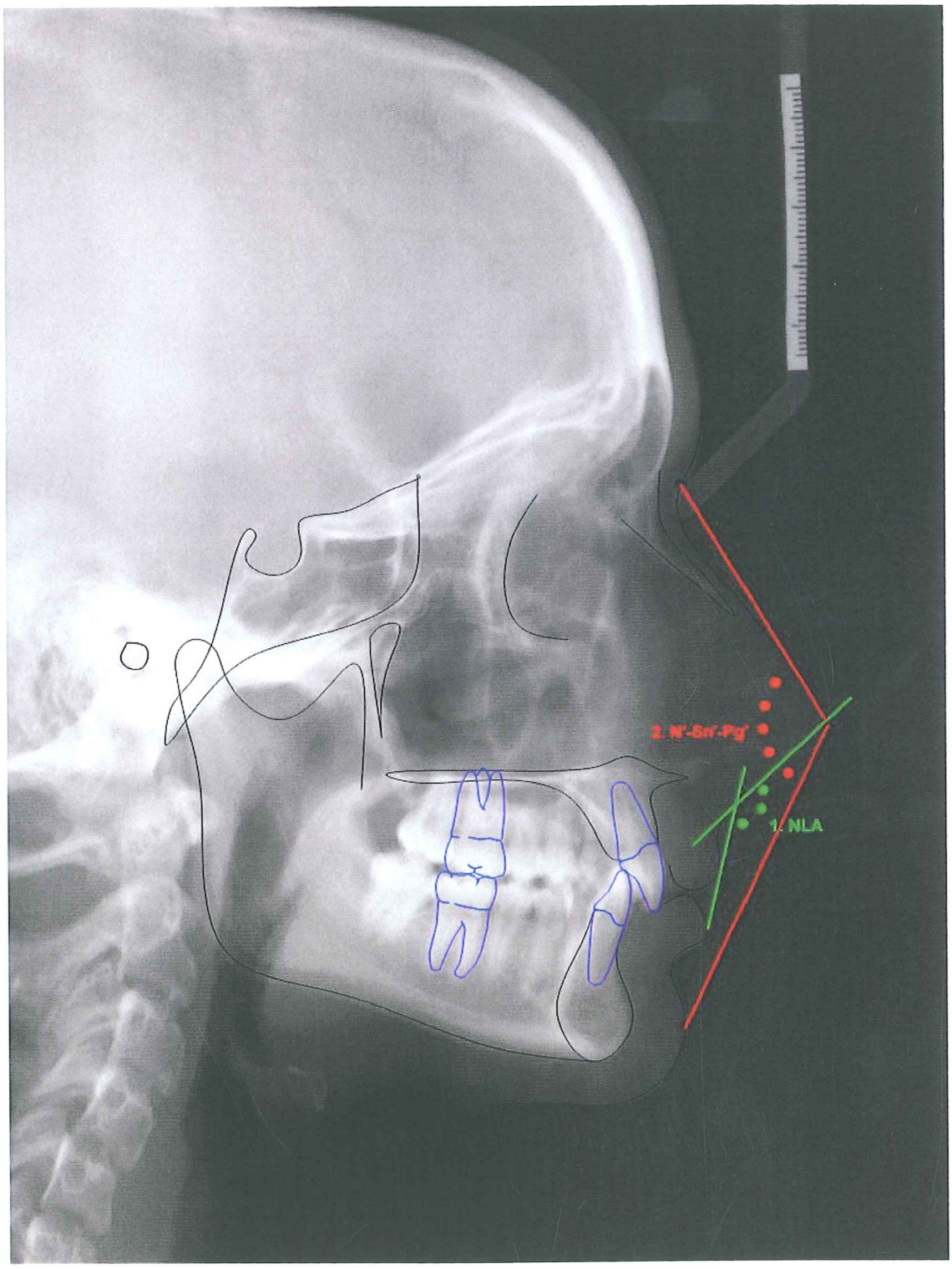


Figure 16: Angular soft-tissue measurements used in lateral cephalometric analysis.

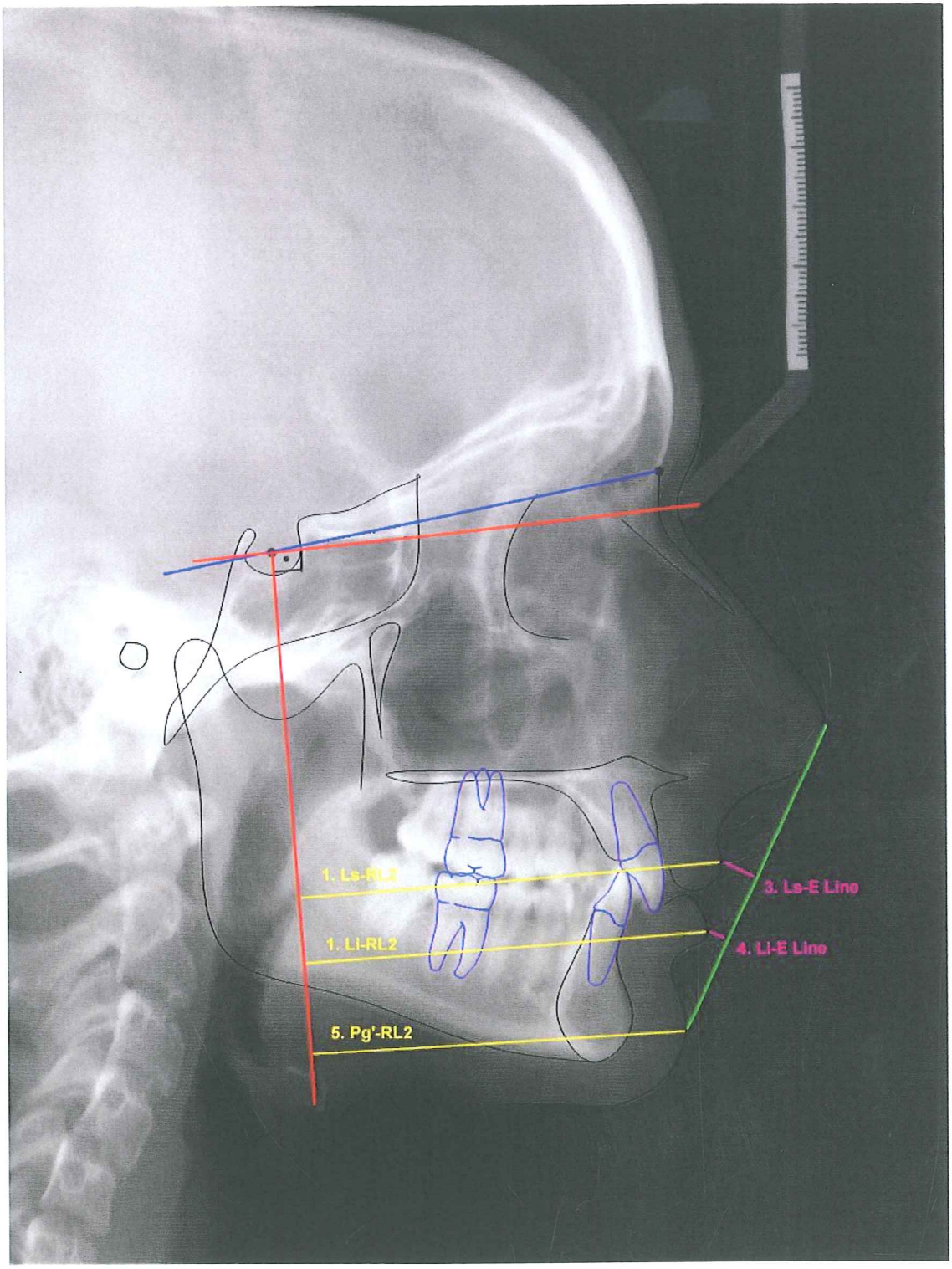


Figure 17: Linear soft-tissue measurements used in lateral cephalometric analysis.

5.2.5. Statistical Method

Statistical calculations were performed with NCSS 2007 program for Windows. Besides standard descriptive statistical calculations (mean and standard deviation), treatment group repeated measures of ANOVA was used to determine the differences in measurement at each time point. When $p < 0.05$, student Newman Keuls multiple comparisons tests were used for pair wise comparisons. Mann Whitney-U test (MW) was used in the comparison of treatment changes. Intraclass correlation coefficient was used reliability of measurements. Statistical significance level was established at $p< 0,05$.

5.2.5.1. Error of the Method

To evaluate intraobserver measurement error in cephalometric tracings, 5 patients were selected at random and 3 lateral cephalograms of each patient were hand-traced again by the same observer. The reliability of the measurements was statistically evaluated by calculating the intraclass correlation coefficient and intraobserver measurement correspondence. The results were evaluated within a 95% confidence interval.

6. RESULTS

6.1. Method Error Evaluation

To evaluate intraobserver measurement error in cephalometric tracings, 5 patients were selected at random and 3 lateral cephalograms of each patient were hand-traced again by the same observer. The reliability of the measurements was statistically evaluated by calculating the intraclass correlation coefficient and intraobserver measurement correspondence. The results were evaluated within a 95% confidence interval. Findings suggest that measurements are reliable and within acceptable limits (Table 4-6).

Table 4: Evaluation of cephalometric tracing reliability of skeletal measurements by using **intraclass correlation coefficient**.

			Skeletal Measurements	95% Confidence Interval	Intraclass Correlation Coefficient	Significance
Angular	Sagittal	1	SNA	(0,947-0,994)	0,982	*
		2	SNB	(0,936-0,993)	0,979	*
		3	ANB	(0,934-0,993)	0,978	*
		4	N-A-Pg	(0,915-0,990)	0,972	*
	Vertical	5	SN/PP	(0,865-0,962)	0,887	*
		6	SN/MP	(0,962-0,996)	0,987	*
		7	PP/MP	(0,911-0,990)	0,970	*
Linear	Sagittal	8	SL	(0,908-0,998)	0,987	*
		9	SE	(0,923-0,997)	0,975	*
		10	Go-Gn	(0,936-0,999)	0,991	*
		11	Ar-Pg	(0,995-0,999)	0,998	*
		12	Pg-RL2	(0,953-0,999)	0,993	*
		13	Ar-RL2	(0,913-0,963)	0,932	*
		14	Mandibular Length	(0,884-0,984)	0,914	*
		15	A-RL2	(0,975-0,999)	0,997	*
	Vertical	16	ANSMe/NMe	(0,990-0,998)	0,995	*
		17	Jarabak	(0,881-0,987)	0,904	*
		18	Gonial Ratio	(0,987-0,998)	0,998	*
		19	Ar-Go	(0,921-0,998)	0,989	*
		20	A-RL1	(0,960-0,999)	0,994	*

Table 5: Evaluation of cephalometric tracing reliability of dental measurements by using **intraclass correlation coefficient**.

		Dental Measurements	95% Confidence Interval	Intraclass Correlation Coefficient	Significance
Angular	1	SN/OP	(0,866-0,929)	0,887	*
	2	OP/MP	(0,788-0,954)	0,862	*
	3	PP/OP	(0,858-0,950)	0,951	*
	4	U1/SN	(0,885-0,998)	0,984	*
	5	IMPA	(0,984-0,999)	0,998	*
Linear	6	Holdaway	(0,889-0,998)	0,985	*
	7	U1-RL2	(0,909-0,994)	0,959	*
	8	U1-RL1	(0,899-0,998)	0,986	*
	9	L1-RL2	(0,951-0,999)	0,993	*
	10	L1-RL1	(0,967-0,999)	0,995	*
	11	U6-RL2	(0,859-0,997)	0,980	*
	12	U6-RL1	(0,975-0,998)	0,996	*
	13	L6-RL2	(0,965-0,999)	0,994	*
	14	L6-RL1	(0,907-0,992)	0,983	*
	15	OJ	(0,917-0,996)	0,969	*
	16	OB	(0,955-0,999)	0,994	*

Table 6: Evaluation of cephalometric tracing reliability of soft-tissue measurements by using **intraclass correlation coefficient**.

		Soft-tissue Measurements	95% Confidence Interval	Intraclass Correlation Coefficient	Significance
Angular	1	Nasolabial	(0,911-0,998)	0,988	*
	2	N'-Sn'-Pg'	(0,907-0,991)	0,934	*
Linear	3	Lab. Sup.-E line	(0,954-0,999)	0,994	*
	4	Lab. Inf.-E line	(0,989-0,999)	0,998	*
	5	Lab. Sup.-RL2	(0,863-0,988)	0,911	*
	6	Lab. Inf.-RL2	(0,892-0,972)	0,916	*
	7	Pg'-RL2	(0,809-0,996)	0,973	*

6.2. Evaluation of Lateral Cephalograms

Statistical evaluations of 43 parameters used in the study are shown in tables (Table 7-15) (Figure 18-41).

6.2.1. Evaluation of Skeletal Changes between T0 and T1

Skeletal changes between T0 and T1 are shown in Table 7 and Figure 18-21.

Statistically significant changes were observed in five of twenty skeletal parameters.

Table 7: Statistical evaluation of skeletal changes between T0 and T1.

X: Mean values at T0 and T1

S: Standard deviation

D: Mean value of the difference between T0 and T1.

* : p<0,05 ** : p<0,01 *** : p<0,001

			Skeletal Measurements	T0		T1		T0-T1		P	Signifi-cance
				X	S	X	S	D	S		
Angular	Sagittal	1	SNA	81	3,86	80,84	3,78	0,16	1,38	0,566	
		2	SNB	75,84	2,81	75,68	3,07	0,16	1,18	0,504	
		3	ANB	5,16	2,36	5,16	2,27	0	1,29	1	
		4	N-A-Pg	172,44	6,2	174,08	5,36	-1,64	4,54	0,083	
	Vertical	5	SN/PP	7,04	2,51	7,36	3,11	-0,32	1,6	0,327	
		6	SN/MP	32,2	4,9	32,48	4,47	-0,28	2,07	0,506	
		7	PP/MP	26,04	4,58	25,88	4,41	0,16	2,41	0,743	
Linear	Sagittal	8	SL	48,56	6,52	48,6	6,87	-0,04	2,19	0,928	
		9	SE	20	3,04	20,68	2,56	-0,68	2,14	0,124	
		10	Go-Gn	75,12	4,92	76,08	5,48	-0,96	2,21	**0,04**	*
		11	Ar-Pg	103,8	6,16	105,72	6,83	-1,92	2,27	**0,0001**	***
		12	Pg-RL2	62,44	7,33	62,72	7,86	-0,28	2,64	0,601	
		13	Ar-RL2	16,2	2,75	16,6	2,63	-0,4	1,66	0,24	
		14	Mandibular Length	78,64	7,5	79,32	7,77	-0,68	2,93	0,257	
		15	A-RL2	70,48	5,08	71,16	5,15	-0,68	1,44	**0,026**	*
	Vertical	16	ANSMe/NMe	0,545	0,018	0,541	0,018	0,004	0,013	0,191	
		17	Jarabak	0,647	0,037	0,649	0,043	-0,002	0,021	0,679	
		18	Gonial Ratio	0,763	0,075	0,75	0,071	0,013	0,033	0,055	
		19	Ar-Go	43,48	4,97	44,84	4,98	-1,36	2,4	**0,009**	**
		20	A-RL1	50	2,1	50,92	2,83	-0,92	1,71	**0,013**	*

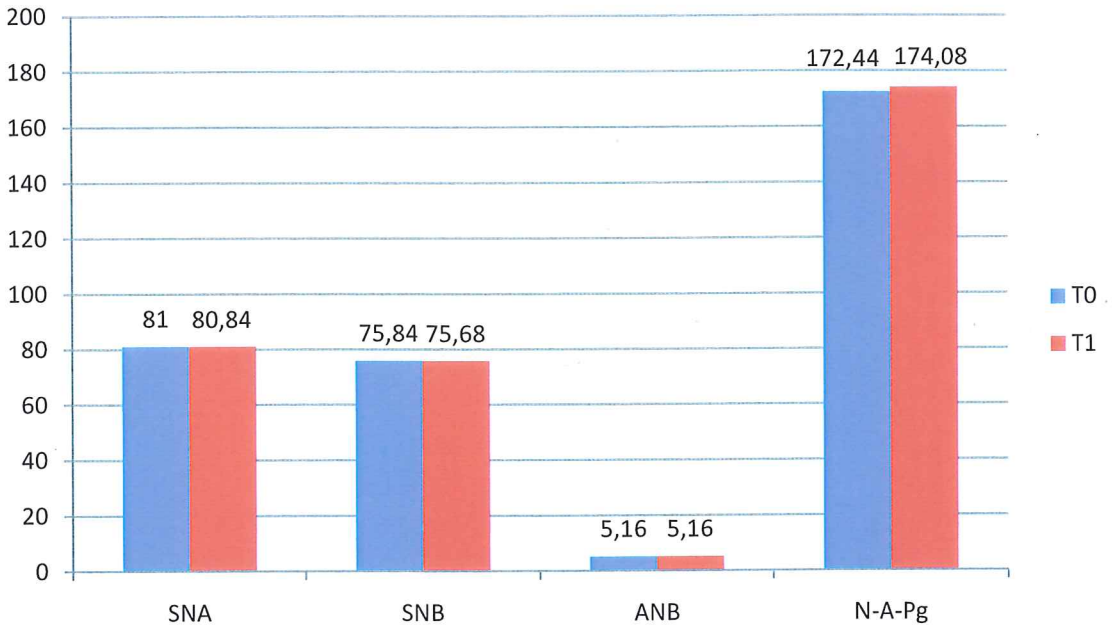


Figure 18: Sagittal angular skeletal changes between T0 and T1.

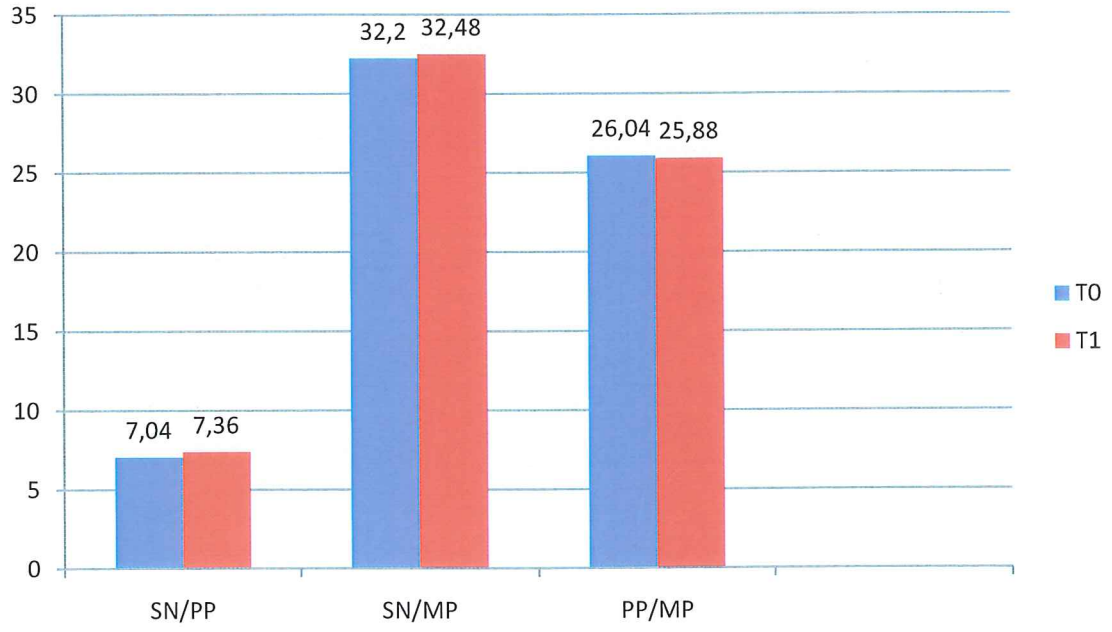


Figure 19: Vertical angular skeletal changes between T0 and T1.

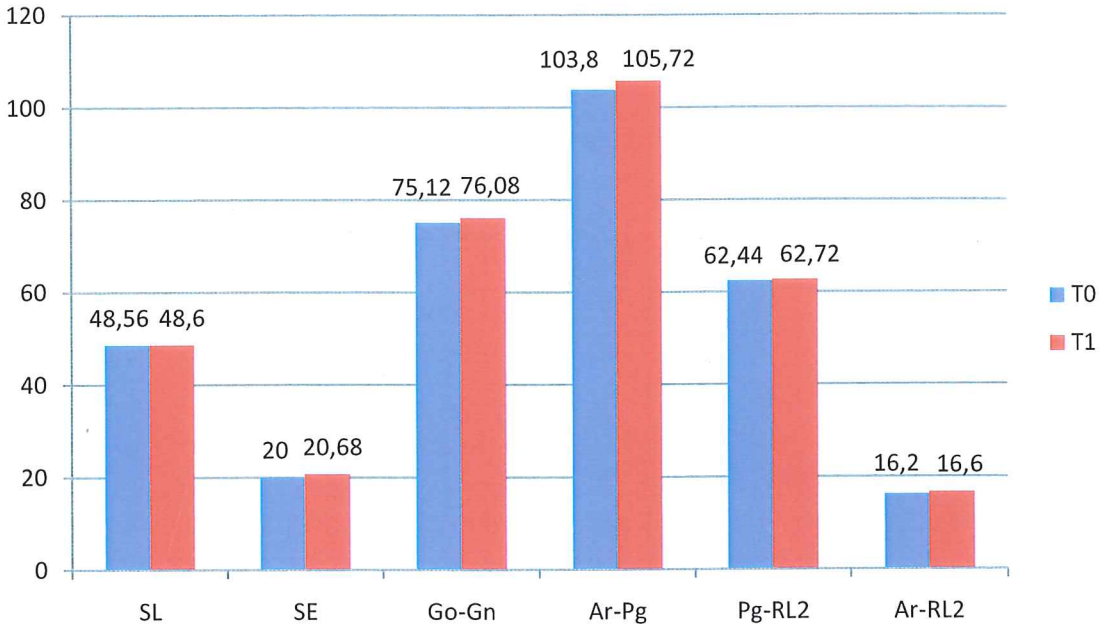


Figure 20: Sagittal linear skeletal changes between T0 and T1.

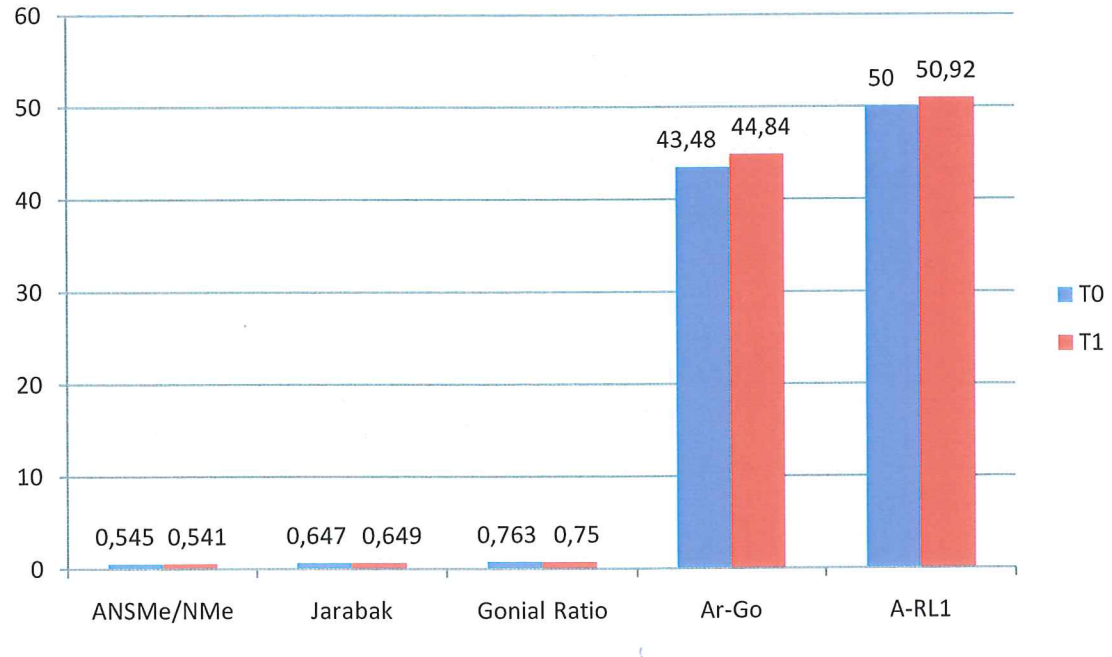


Figure 21: Vertical linear skeletal changes between T0 and T1.

6.2.2. Evaluation of Dental Changes between T0 and T1

Dental changes between T0 and T1 are shown in Table 8 and Figure 22-23.

Statistically significant changes were observed in six of sixteen dental parameters.

Table 8: Statistical evaluation of dental changes between T0 and T1.

X: Mean values at T0 and T1

S: Standard deviation

D: Mean value of the difference between T0 and T1.

* : p<0,05 ** : p<0,01 *** : p<0,001

		Dental Measurements	T0		T1		T0-T1		P	Signifi-cance
			X	S	X	S	D	S		
Angular	1	SN/OP	15,84	5,25	13,72	4,95	2,12	3,64	**0,008**	**
	2	OP/MP	15,84	4,8	19,08	4,16	-3,24	4,74	**0,002**	**
	3	PP/OP	10,08	4,51	7,08	4,2	3	3,67	**0,0001**	***
	4	U1/SN	110,52	7,02	109,8	8,05	0,72	8,12	0,662	
	5	IMPA	96,24	5,64	96,52	5,3	-0,28	5,11	0,787	
Linear	6	Holdaway	1,68	3,01	1,8	2,45	-0,12	1,48	0,689	
	7	U1-RL2	77,12	6,15	77	6,87	0,12	2,62	0,821	
	8	U1-RL1	72,88	4,16	73,56	4,55	-0,68	1,8	0,071	
	9	L1-RL2	68,48	5,91	69	6,01	-0,52	1,9	0,183	
	10	L1-RL1	66,52	4,53	68,68	4,6	-2,16	2,73	**0,001**	**
	11	U6-RL2	40,4	4,77	41,16	4,96	-0,76	2,57	0,152	
	12	U6-RL1	65,4	3,91	66,64	3,89	-1,24	3,15	0,061	
	13	L6-RL2	39,36	4,8	40,12	4,89	-0,76	2,33	0,116	
	14	L6-RL1	65,72	3,88	67,24	3,87	-1,52	3,12	**0,023**	*
	15	OJ	8,56	2,27	8,04	2,42	0,52	2,49	0,306	
	16	OB	6,48	2,54	4,88	1,76	1,6	2,45	**0,003**	**

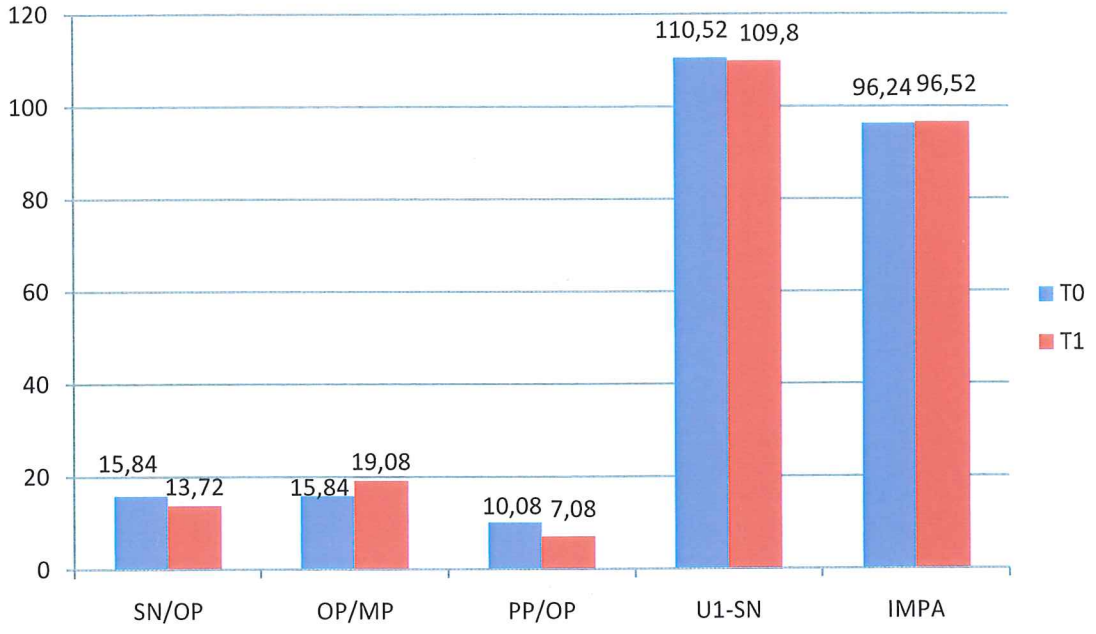


Figure 22: Angular dental changes between T0 and T1.

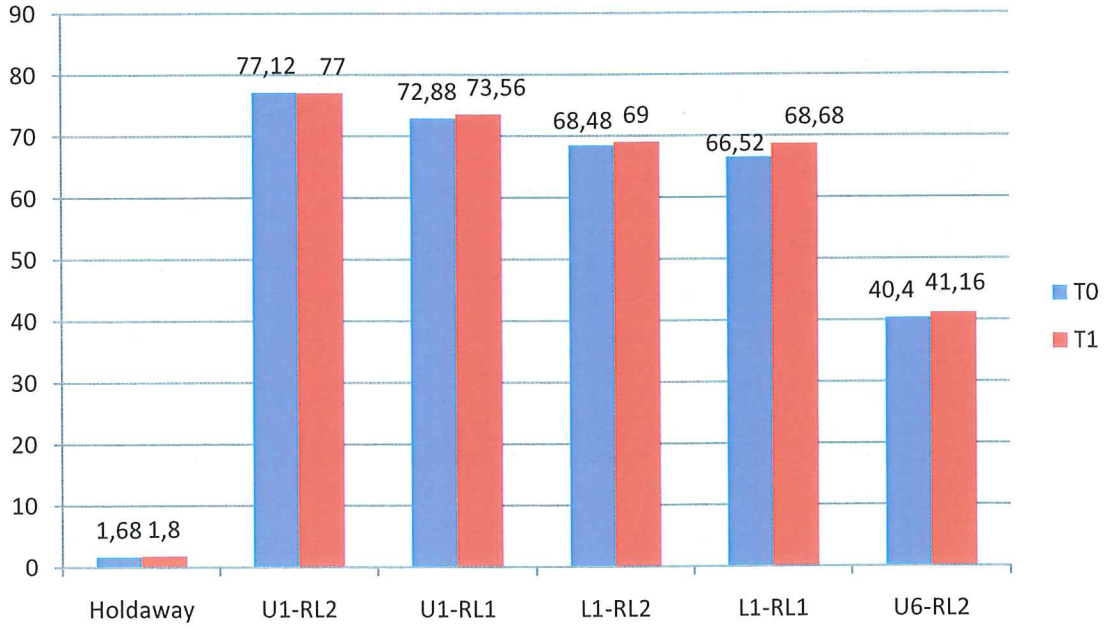


Figure 23: Linear dental changes between T0 and T1.

6.2.3. Evaluation of Soft-tissue Changes between T0 and T1

Soft-tissue changes between T0 and T1 are shown in Table 9 and Figure 24-25.

Statistically significant changes were observed in two of seven soft-tissue parameters.

Table 9: Statistical evaluation of soft-tissue changes between T0 and T1.

X: Mean values at T0 and T1

S: Standard deviation

D: Mean value of the difference between T0 and T1.

* : p<0,05 ** : p<0,01 *** : p<0,001

		Soft-tissue Measurements	T0		T1		T0-T1		P	Signifi-cance
			X	S	X	S	D	S		
Angular	1	Nasolabial	117,2	10,25	116,24	9,63	0,96	4,57	0,304	
	2	N'-Sn'-Pg'	154,4	5,32	153,04	4,75	1,36	3,33	0,052	
Linear	3	Lab. Sup.-E line	-0,24	2,73	-0,32	2,17	0,08	1,55	0,798	
	4	Lab. Inf.-E line	1,28	2,7	1,24	2,73	0,04	2,15	0,927	
	5	Lab. Sup.-RL2	88,48	5,77	90,24	6,34	-1,76	1,83	**0,0001**	***
	6	Lab. Inf.-RL2	84,6	6,29	86,04	6,88	-1,44	1,96	**0,001**	**
	7	Pg'-RL2	75,04	6,48	75,84	7,19	-0,8	2	0,057	

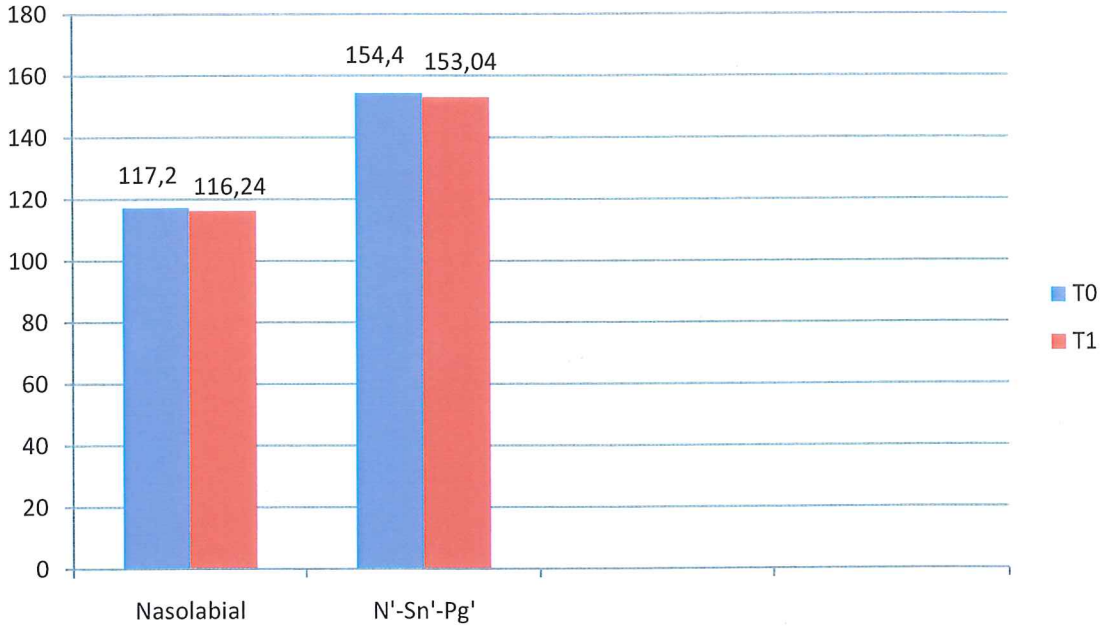


Figure 24: Angular soft-tissue changes between T0 and T1.

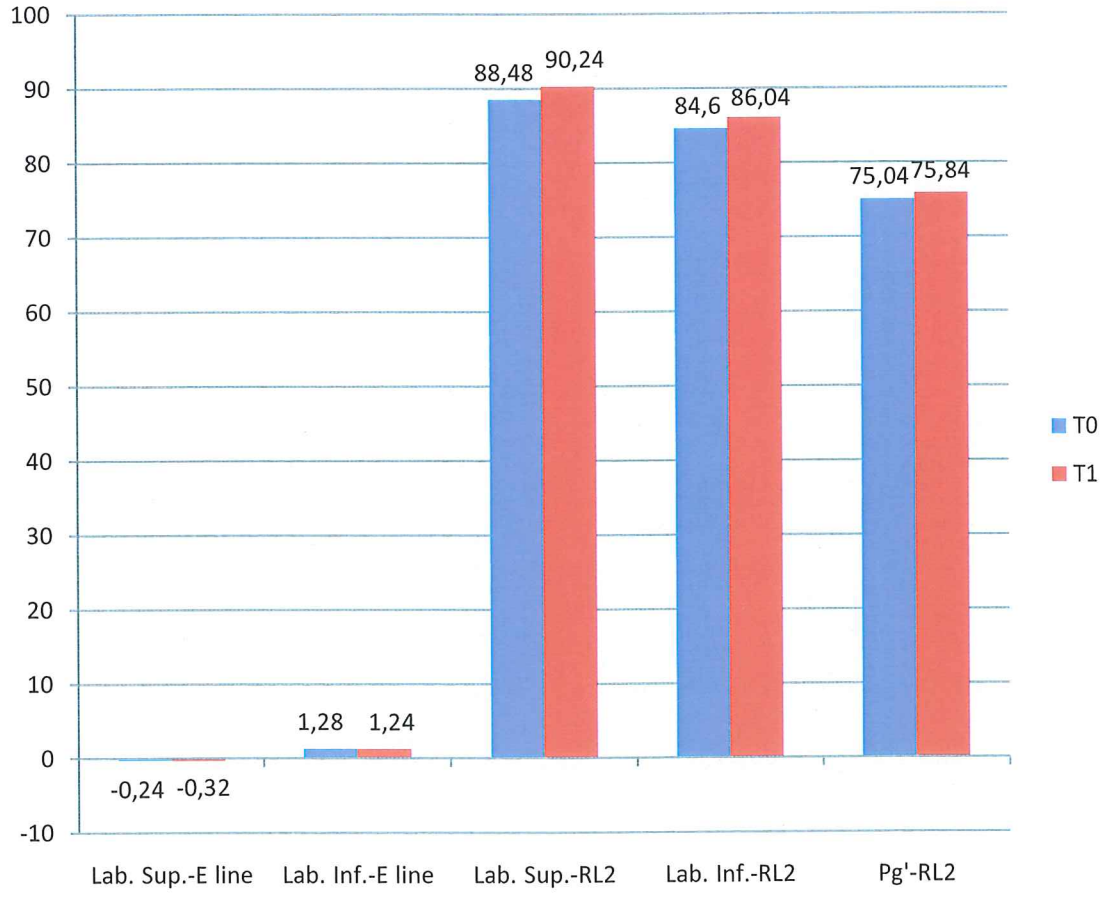


Figure 25: Linear soft-tissue changes between T0 and T1.

6.2.4. Evaluation of Skeletal Changes between T1 and T2

Skeletal changes between T1 and T2 are shown in Table 10 and Figure 26-29.

Statistically significant changes were observed in ten of twenty skeletal parameters.

Table 10: Statistical evaluation of skeletal changes between T1 and T2.

X: Mean values at T1 and T2

S: Standard deviation

D: Mean value of the difference between T1 and T2

* : p<0,05 ** : p<0,01 *** : p<0,001

			Skeletal Measurements	T1		T2		T1-T2		P	Signifi-cance
				X	S	X	S	D	S		
Angular	Sagittal	1	SNA	80,84	3,78	79,52	3,41	1,32	1,77	**0,001**	**
		2	SNB	75,68	3,07	75,96	3,02	-0,28	1,34	0,306	
		3	ANB	5,16	2,27	3,56	1,96	1,6	1,71	**0,0001**	***
		4	N-A-Pg	174,08	5,36	176,04	4,56	-1,96	3,27	**0,006**	**
	Vertical	5	SN/PP	7,36	3,11	7,68	2,82	-0,32	2,16	0,465	
		6	SN/MP	32,48	4,47	33,44	5,26	-0,96	2,17	**0,037**	*
		7	PP/MP	25,88	4,41	25,96	4,8	-0,08	2,16	0,855	
Linear	Sagittal	8	SL	48,6	6,87	49	7,72	-0,4	2,57	0,443	
		9	SE	20,68	2,56	20,8	2,87	-0,12	1,59	0,709	
		10	Go-Gn	76,08	5,48	77,28	5,4	-1,2	1,98	**0,006**	**
		11	Ar-Pg	105,72	6,83	107,76	6,81	-2,04	1,95	**0,0001**	***
		12	Pg-RL2	62,72	7,86	63,72	7,96	-1	1,66	**0,006**	**
		13	Ar-RL2	16,6	2,63	16,92	3,15	-0,32	1,35	0,246	
		14	Mandibular Length	79,32	7,77	80,64	8,12	-1,32	2,08	**0,004**	**
		15	A-RL2	71,16	5,15	70,24	5,8	0,92	2	**0,03**	*
	Vertical	16	ANSMe/NMe	0,541	0,018	0,546	0,014	-0,005	0,015	0,116	
		17	Jarabak	0,649	0,043	0,647	0,04	0,001	0,016	0,683	
		18	Gonial Ratio	0,75	0,071	0,749	0,079	0,001	0,032	0,846	
		19	Ar-Go	44,84	4,98	45,72	4,98	-0,88	2,3	0,067	
		20	A-RL1	50,92	2,83	52,2	2,94	-1,28	2,17	**0,007**	**

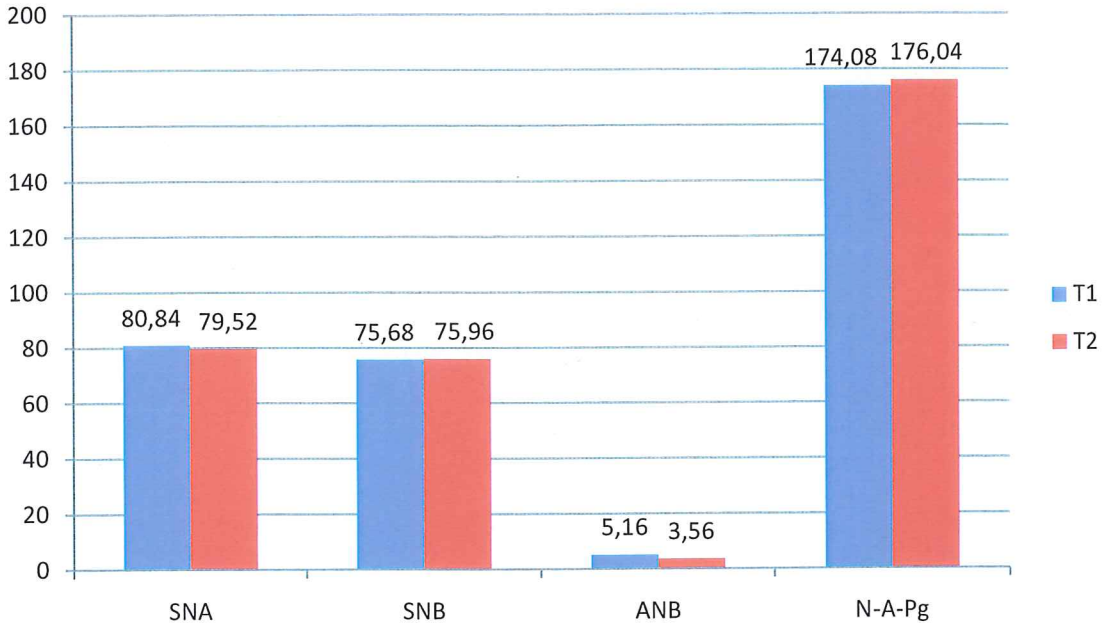


Figure 26: Sagittal angular skeletal changes between T1 and T2.

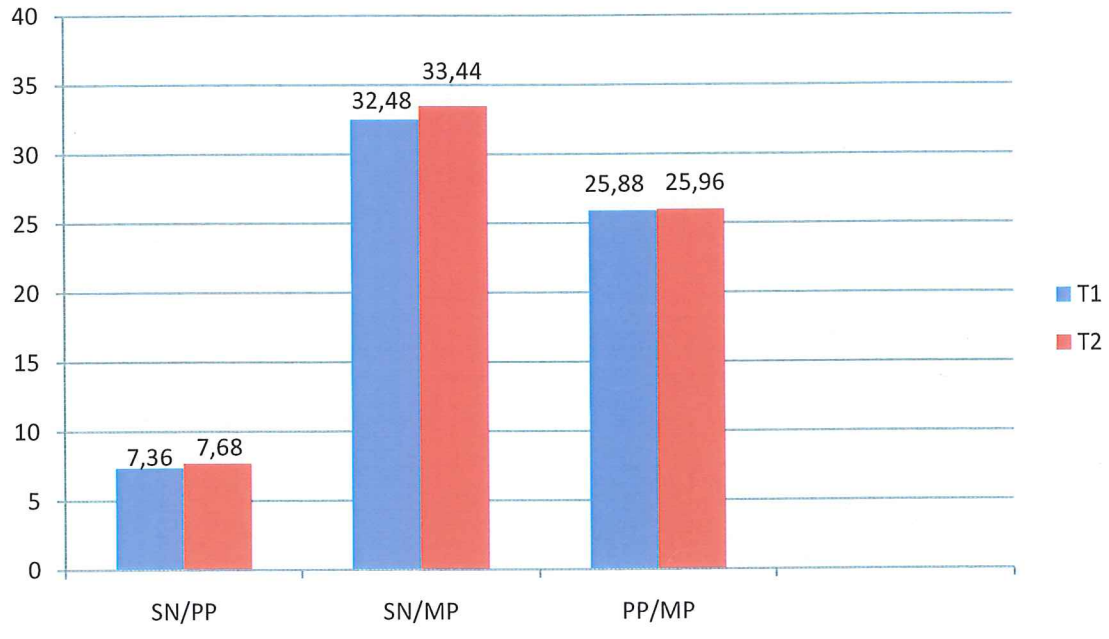


Figure 27: Vertical angular skeletal changes between T1 and T2.

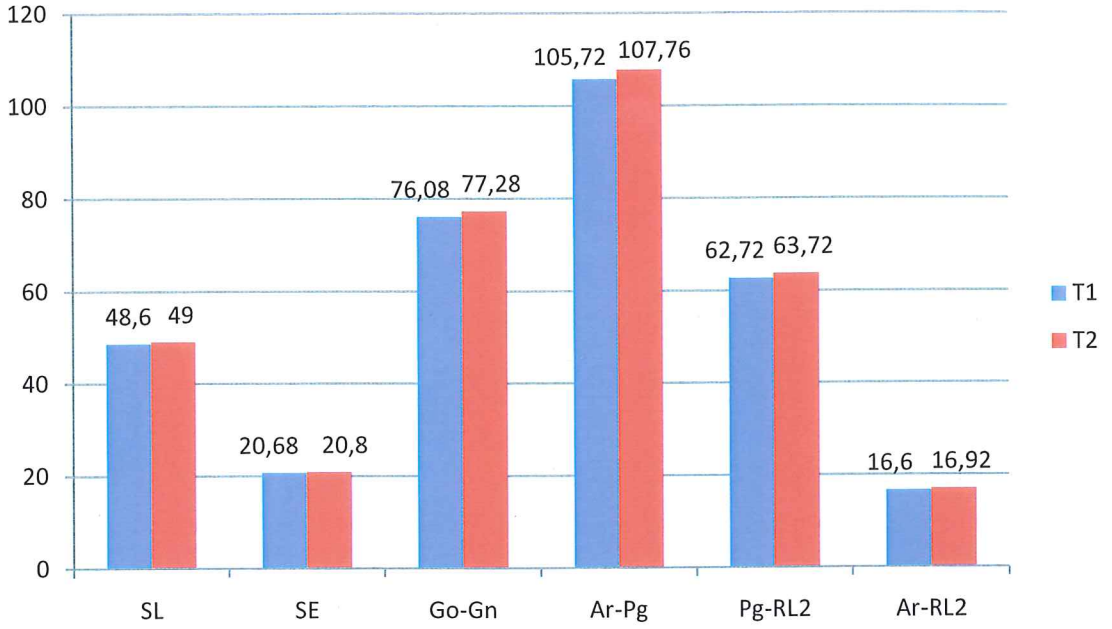


Figure 28: Sagittal linear skeletal changes between T1 and T2.

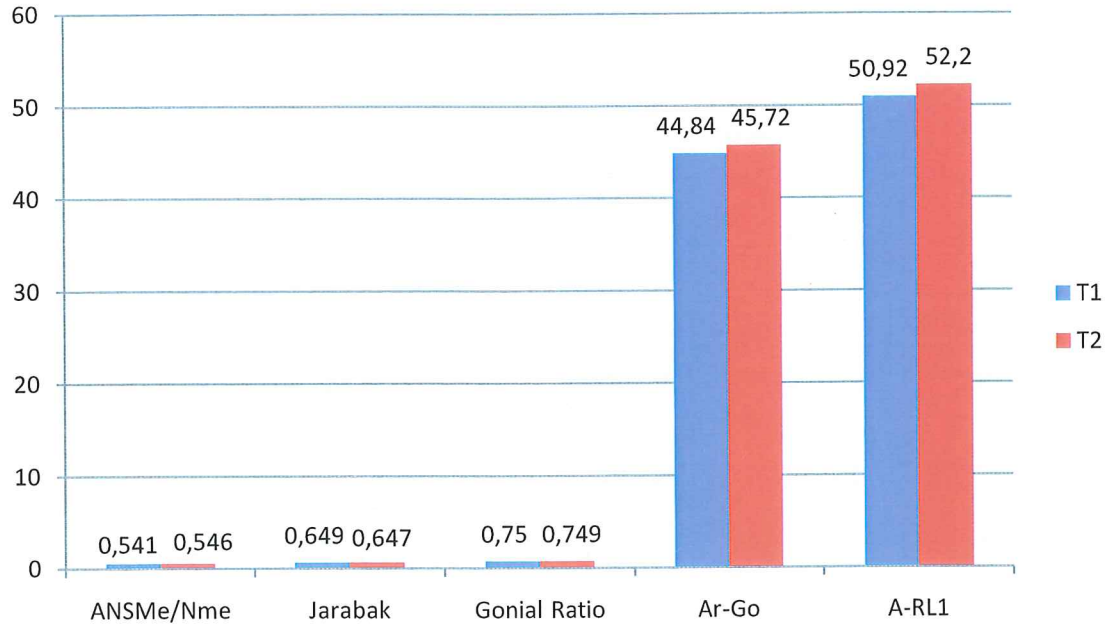


Figure 29: Vertical linear skeletal changes between T1 and T2.

6.2.5. Evaluation of Dental Changes between T1 and T2

Dental changes between T1 and T2 are shown in Table 11 and Figure 30-31.

Statistically significant changes were observed in thirteen of sixteen dental parameters.

Table 11: Statistical evaluation of dental changes between T1 and T2.

X: Mean values at T1 and T2

S: Standard deviation

D: Mean value of the difference between T1 and T2

* : p<0,05 ** : p<0,01 *** : p<0,001

		Dental Measurements	T1		T2		T1-T2		P	Signifi-cance
			X	S	X	S	D	S		
Angular	1	SN/OP	13,72	4,95	18,36	5,69	-4,64	5,21	**0,0001**	***
	2	OP/MP	19,08	4,16	14,2	4,59	4,88	3,32	**0,0001**	***
	3	PP/OP	7,08	4,2	11,2	5,1	-4,12	3,62	**0,0001**	***
	4	U1/SN	109,8	8,05	107,6	6,05	2,2	7,05	0,132	
	5	IMPA	96,52	5,3	105,56	6,55	-9,04	3,92	**0,0001**	***
Linear	6	Holdaway	1,8	2,45	5,08	2,61	-3,28	1,31	**0,0001**	***
	7	U1-RL2	77	6,87	75	6,9	2	1,83	**0,0001**	***
	8	U1-RL1	73,56	4,55	75,92	4,16	-2,36	2,06	**0,0001**	***
	9	L1-RL2	69	6,01	72,08	6,44	-3,08	2,64	**0,0001**	***
	10	L1-RL1	68,68	4,6	74,2	4,33	-5,52	2,71	**0,0001**	***
	11	U6-RL2	41,16	4,96	40,2	4,81	0,96	2,51	0,068	
	12	U6-RL1	66,64	3,89	66,64	3,97	0	1,85	1	
	13	L6-RL2	40,12	4,89	43,76	4,81	-3,64	2,33	**0,0001**	***
	14	L6-RL1	67,24	3,87	68,04	3,94	-0,8	1,8	**0,036**	*
	15	OJ	8,04	2,42	2,92	1,47	5,12	3,07	**0,0001**	***
	16	OB	4,88	1,76	1,72	1,28	3,16	2,04	**0,0001**	***

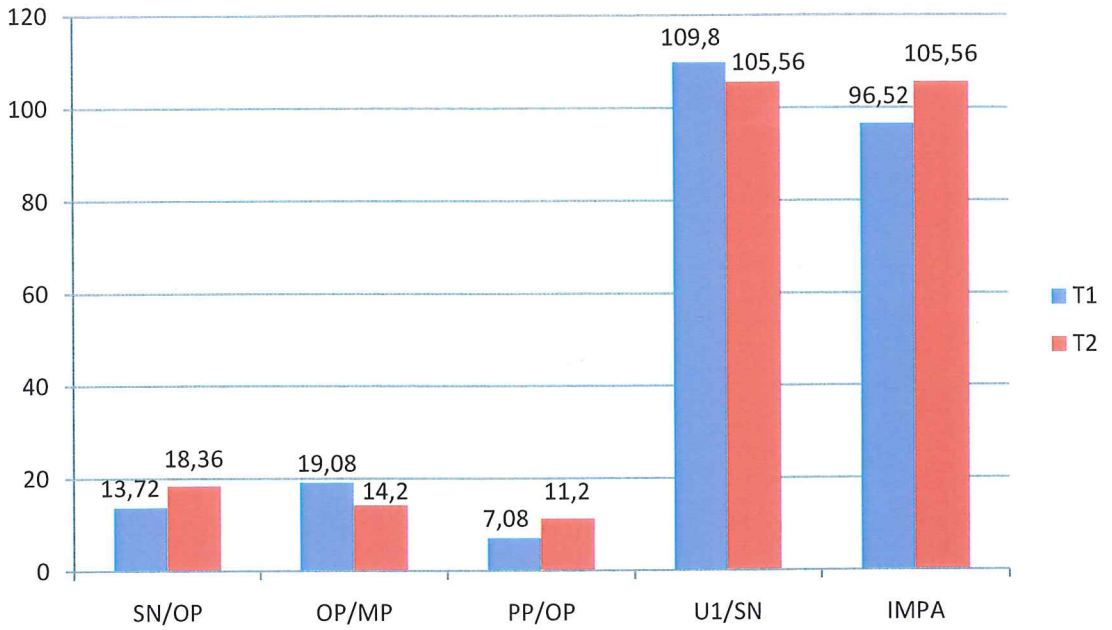


Figure 30: Angular dental changes between T1 and T2.

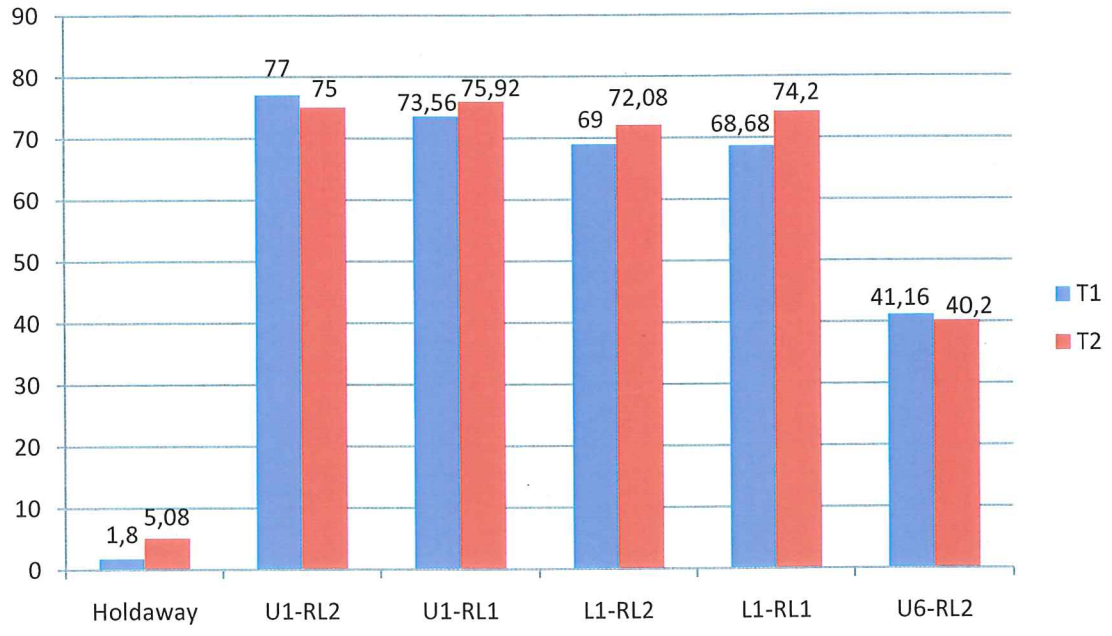


Figure 31: Linear dental changes between T1 and T2.

6.2.6. Evaluation of Soft-tissue Changes between T1 and T2

Soft-tissue changes between T1 and T2 are shown in Table 12 and Figure 32-33.

Statistically significant changes were observed in six of seven soft-tissue parameters.

Table 12: Statistical evaluation of soft-tissue changes between T1 and T2.

X: Mean values at T1 and T2

S: Standard deviation

D: Mean value of the difference between T1 and T2

* : p<0,05 ** : p<0,01 *** : p<0,001

		Soft-tissue Measurements	T1		T2		T1-T2		P	Signifi-cance
			X	S	X	S	D	S		
Angular	1	Nasolabial	116,24	9,63	119,72	10,21	-3,48	6,3	**0,011**	*
	2	N'-Sn'-Pg'	153,04	4,75	155,52	4,41	-2,48	3,19	**0,001**	**
Linear	3	Lab. Sup.-E line	-0,32	2,17	-2,56	2,04	2,24	1,91	**0,0001**	***
	4	Lab. Inf.-E line	1,24	2,73	1,32	2,34	-0,08	1,47	0,788	
	5	Lab. Sup.-RL2	90,24	6,34	89,12	6,98	1,12	1,9	**0,007**	**
	6	Lab. Inf.-RL2	86,04	6,88	87,04	7,54	-1	2,1	**0,026**	*
	7	Pg'-RL2	75,84	7,19	77,28	8,07	-1,44	1,94	**0,001**	**

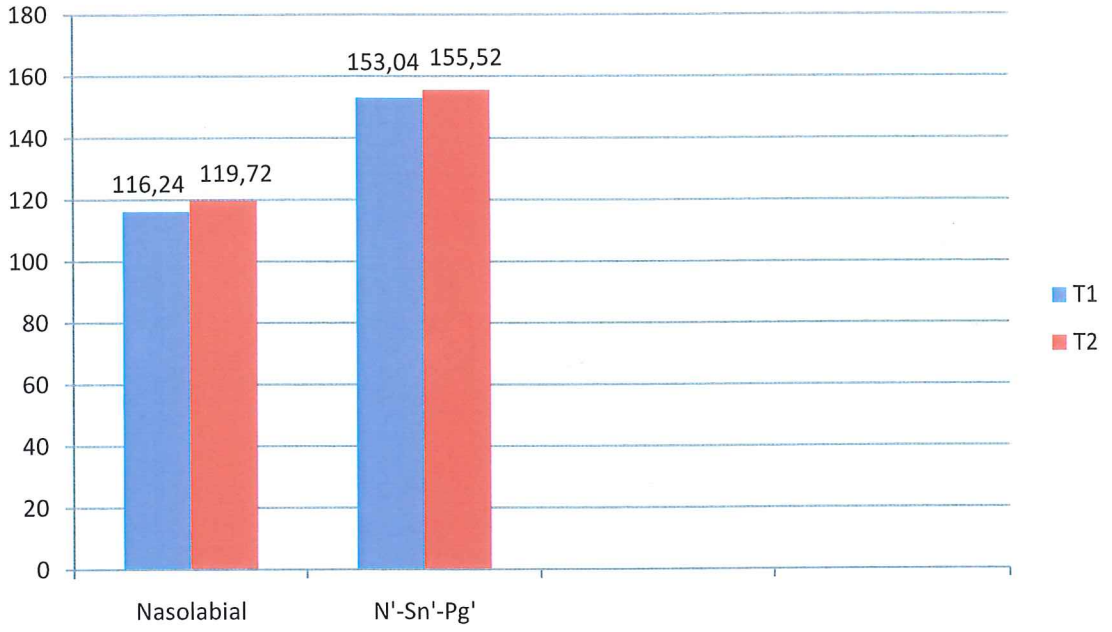


Figure 32: Angular soft-tissue changes between T1 and T2.

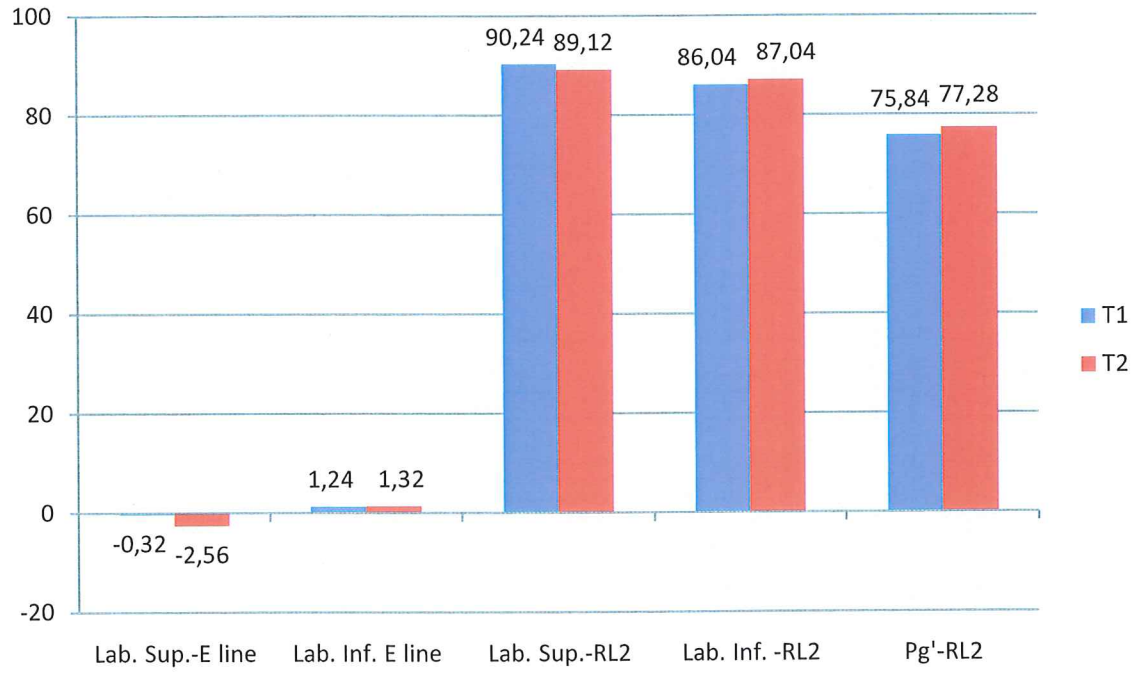


Figure 33: Linear soft-tissue changes between T1 and T2.

6.2.7. Comparison of Treatment Changes between T0-T1 and T1-T2

6.2.7.1. Comparison of Skeletal Treatment Changes between T0-T1 and T1-T2

The changes between T0 and T1 were compared with the changes between T1 and T2 in order to point out the changes which are dependent to FRD treatment.

Statistically significant differences were observed in four of twenty skeletal parameters (Table 13) (Figure 34-37).

Table 13: Comparison of skeletal treatment changes between T0-T1 and T1-T2.

D: Mean value of the difference between T0 and T1/T1 and T2

S: Standard deviation

* : p<0,05 ** : p<0,01 *** : p<0,001

			Skeletal Measurements	T0-T1		T1-T2		P	Significance
				D	S	D	S		
Angular	Sagittal	1	SNA	0,16	1,38	1,32	1,77	**0,02**	*
		2	SNB	0,16	1,18	-0,28	1,34	0,247	
		3	ANB	0	1,29	1,6	1,71	**0,001**	**
		4	N-A-Pg	-1,64	4,54	-1,96	3,27	0,476	
	Vertical	5	SN/PP	-0,32	1,6	-0,32	2,16	0,953	
		6	SN/MP	-0,28	2,07	-0,96	2,17	0,492	
		7	PP/MP	0,16	2,41	-0,08	2,16	0,643	
Linear	Sagittal	8	SL	-0,04	2,19	-0,4	2,57	0,616	
		9	SE	-0,68	2,14	-0,12	1,59	0,54	
		10	Go-Gn	-0,96	2,21	-1,2	1,98	0,783	
		11	Ar-Pg	-1,92	2,27	-2,04	1,95	0,694	
		12	Pg-RL2	-0,28	2,64	-1	1,66	0,148	
		13	Ar-RL2	-0,4	1,66	-0,32	1,35	0,756	
		14	Mandibular Length	-0,68	2,93	-1,32	2,08	0,373	
		15	A-RL2	-0,68	1,44	0,92	2	**0,006**	**
	Vertical	16	ANSMe/NMe	0,004	0,013	-0,005	0,015	**0,026**	*
		17	Jarabak	-0,002	0,021	0,001	0,016	0,648	
		18	Gonial Ratio	0,013	0,033	0,001	0,032	0,273	
		19	Ar-Go	-1,36	2,4	-0,88	2,3	0,428	
		20	A-RL1	-0,92	1,71	-1,28	2,17	0,49	

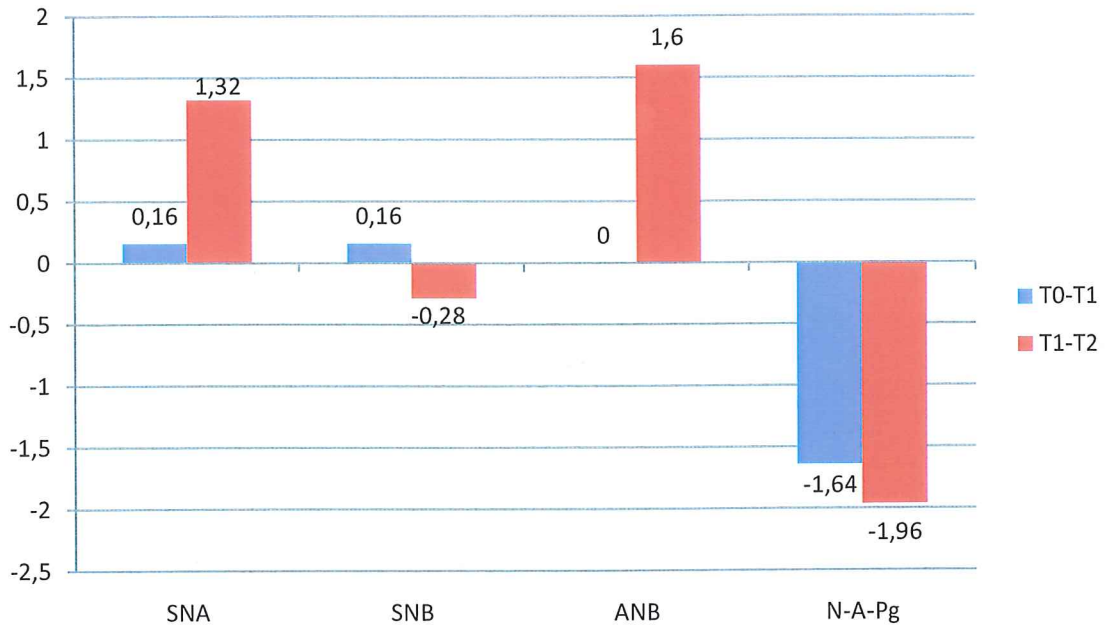


Figure 34: Comparison of sagittal angular skeletal treatment changes between T0-T1 and T1-T2.

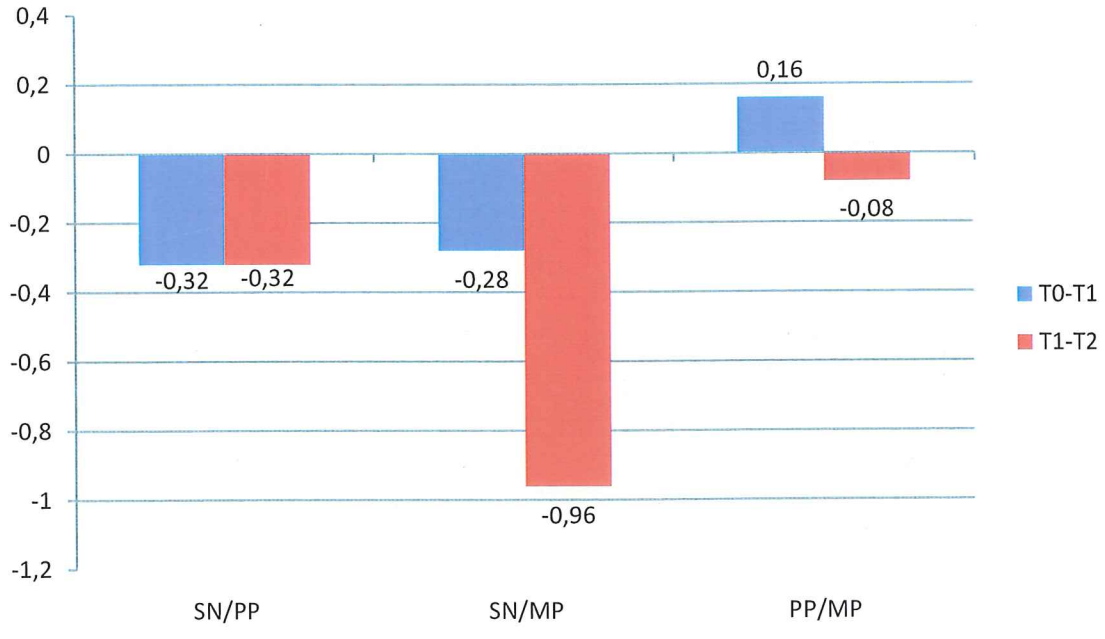


Figure 35: Comparison of vertical angular skeletal treatment changes between T0-T1 and T1-T2.

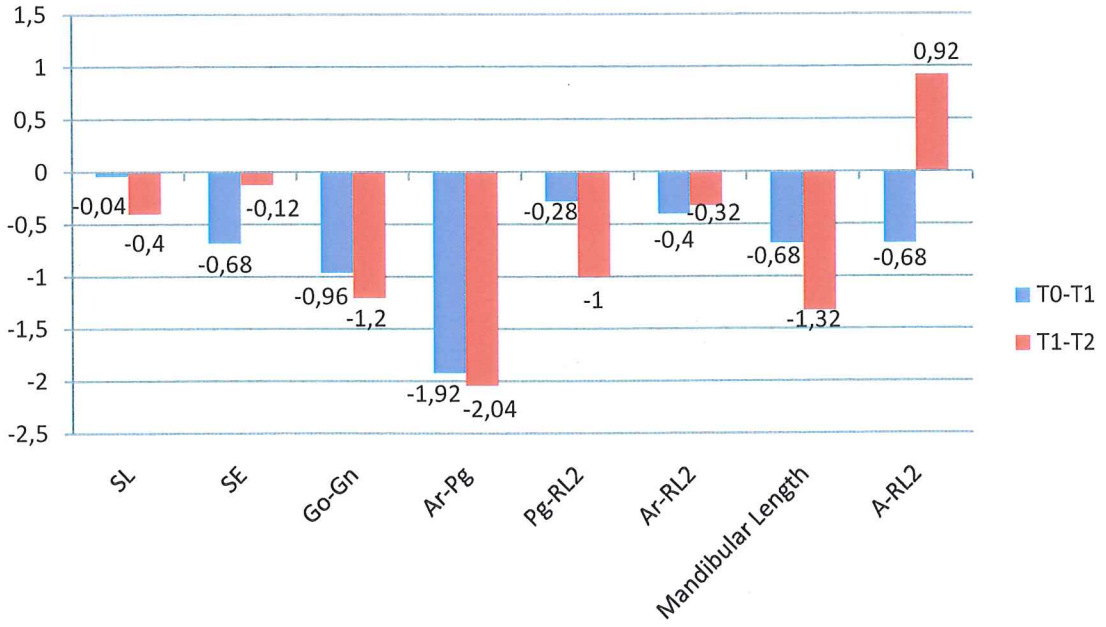


Figure 36: Comparison of sagittal linear skeletal treatment changes between T0-T1 and T1-T2.

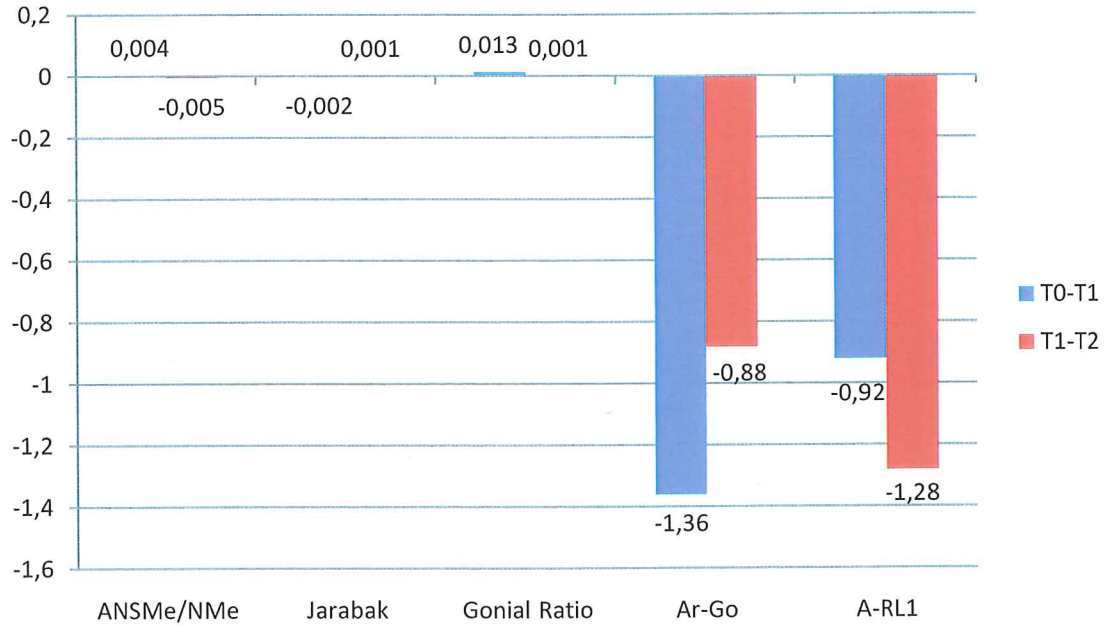


Figure 37: Comparison of vertical linear skeletal treatment changes between T0-T1 and T1-T2.

6.2.7.2. Comparison of Dental Treatment Changes between T0-T1 and T1-T2

Statistically significant differences were observed in thirteen of sixteen dental parameters (Table 14) (Figure 38-39).

Table 14: Comparison of dental treatment changes between T0-T1 and T1-T2.

D: Mean value of the difference between T0 and T1/T1and T2

S: Standard deviation

* : p<0,05 ** : p<0,01 *** : p<0,001

		Dental Measurements	T0-T1		T1-T2		P	Signifi-cance
			D	S	D	S		
Angular	1	SN/OP	2,12	3,64	-4,64	5,21	**0,0001**	***
	2	OP/MP	-3,24	4,74	4,88	3,32	**0,0001**	***
	3	PP/OP	3	3,67	-4,12	3,62	**0,0001**	***
	4	U1/SN	0,72	8,12	2,2	7,05	0,566	
	5	IMPA	-0,28	5,11	-9,04	3,92	**0,0001**	***
Linear	6	Holdaway	-0,12	1,48	-3,28	1,31	**0,0001**	***
	7	U1-RL2	0,12	2,62	2	1,83	**0,006**	**
	8	U1-RL1	-0,68	1,8	-2,36	2,06	**0,006**	**
	9	L1-RL2	-0,52	1,9	-3,08	2,64	**0,0001**	***
	10	L1-RL1	-2,16	2,73	-5,52	2,71	**0,0001**	***
	11	U6-RL2	-0,76	2,57	0,96	2,51	**0,032**	*
	12	U6-RL1	-1,24	3,15	0	1,85	0,122	
	13	L6-RL2	-0,76	2,33	-3,64	2,33	**0,0001**	***
	14	L6-RL1	-1,52	3,12	-0,8	1,8	0,284	
	15	OJ	0,52	2,49	5,12	3,07	**0,0001**	***
	16	OB	1,6	2,45	3,16	2,04	**0,035**	*

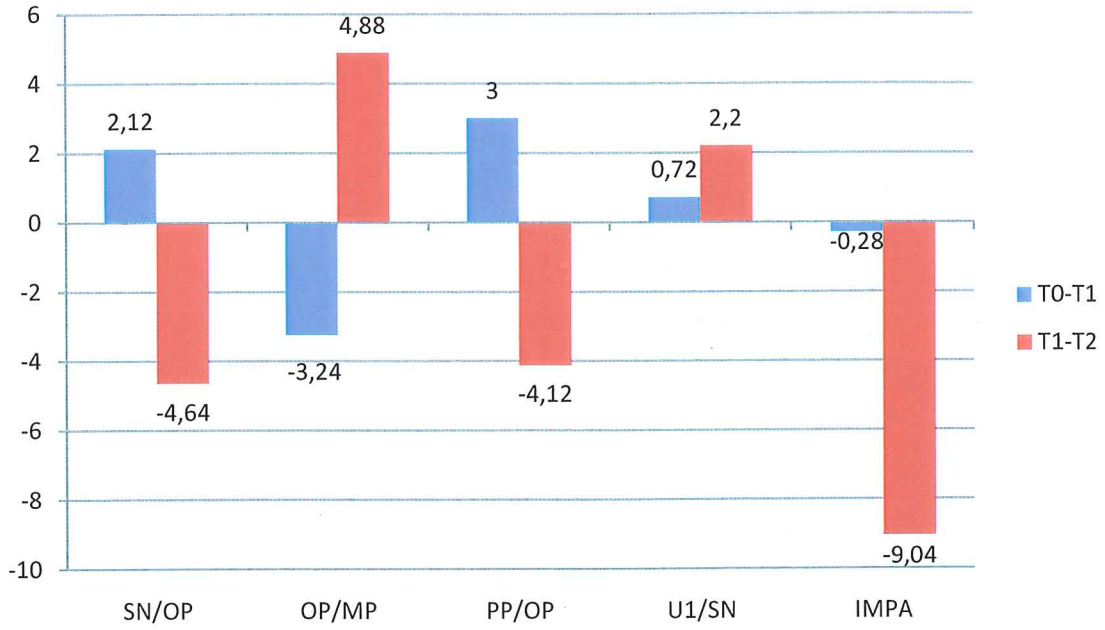


Figure 38: Comparison of angular dental treatment changes between T0-T1 and T1-T2.

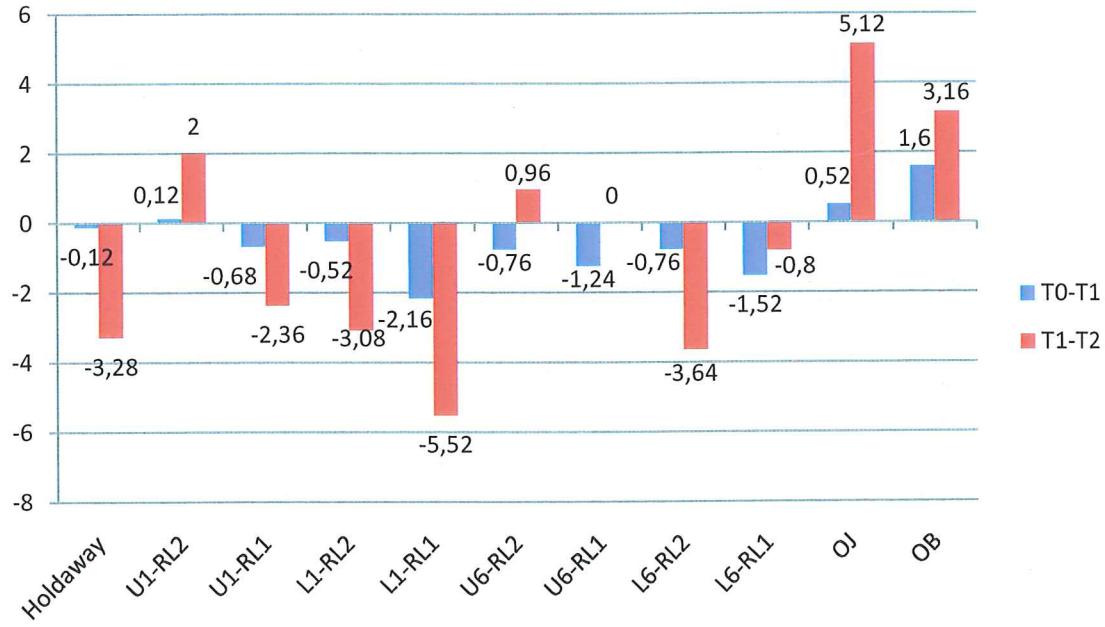


Figure 39: Comparison of linear dental treatment changes between T0-T1 and T1-T2.

6.2.7.3. Comparison of Soft-tissue Treatment Changes between T0-T1 and T1-T2

Statistically significant differences were observed in four of seven soft-tissue parameters (Table 15) (Figure 40-41).

Table 15: Comparison of soft-tissue treatment changes between T0-T1 and T1-T2.

D: Mean value of the difference between T0 and T1/T1 and T2

S: Standard deviation

* : p<0,05 ** : p<0,01 *** : p<0,001

		Soft-tissue Measurements	T0-T1		T1-T2		P	Significance
			D	S	D	S		
Angular	1	Nasolabial	0,96	4,57	-3,48	6,3	**0,009**	**
	2	N'-Sn'-Pg'	1,36	3,33	-2,48	3,19	**0,0001**	***
Linear	3	Lab. Sup.-E line	0,08	1,55	2,24	1,91	**0,0001**	***
	4	Lab. Inf.-E line	0,04	2,15	-0,08	1,47	0,513	
	5	Lab. Sup.-RL2	-1,76	1,83	1,12	1,9	**0,0001**	***
	6	Lab. Inf.-RL2	-1,44	1,96	-1	2,1	0,693	
	7	Pg'-RL2	-0,8	2	-1,44	1,94	0,284	

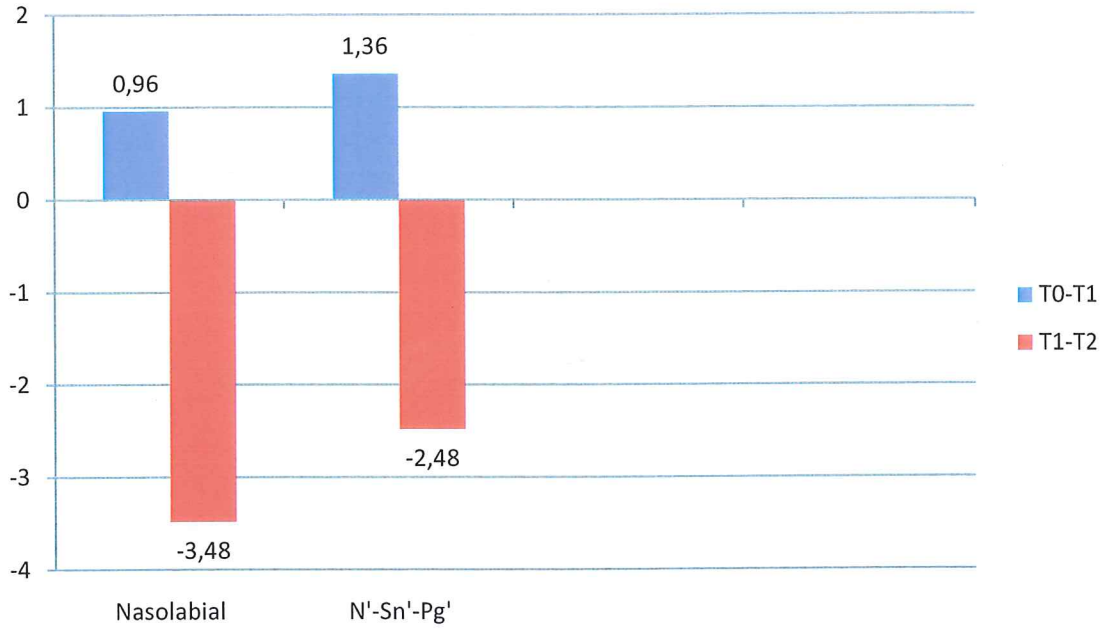


Figure 40: Comparison of angular soft-tissue treatment changes between T0-T1 and T1-T2.

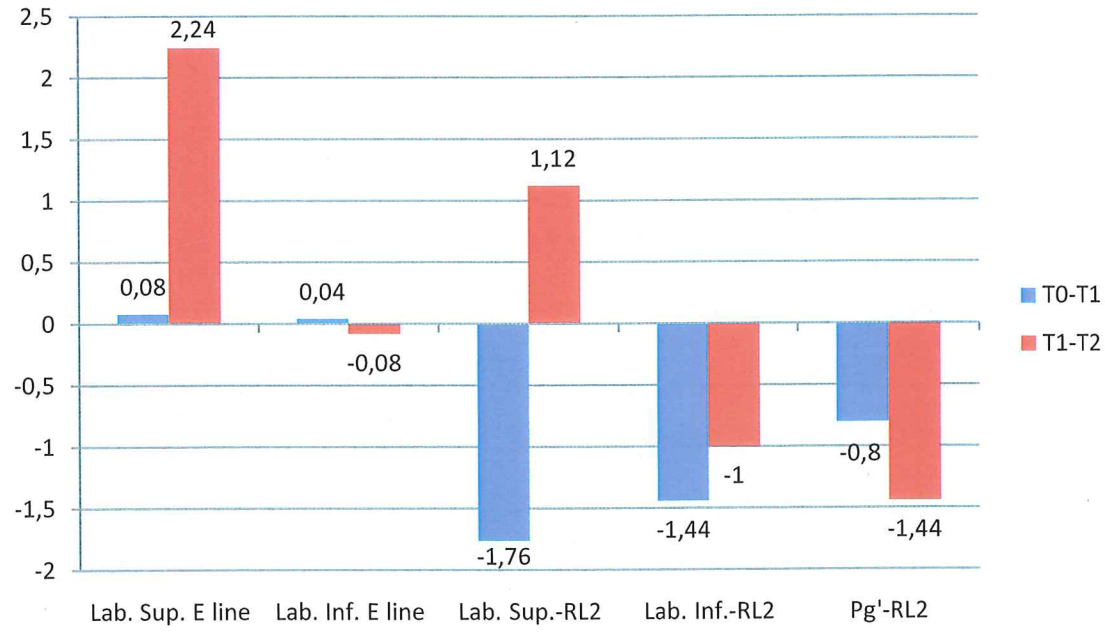


Figure 41: Comparison of linear soft-tissue treatment changes between T0-T1 and T1-T2.

7. DISCUSSION

7.1. Discussion of Aim

Cl II malocclusion is a major and common problem in orthodontic practice. The prevalence of malocclusion varies in different parts of the world among various populations. Proffit reported that it constitutes one-third of all orthodontic problems (293). According to studies on Turkish population, the prevalence of Cl II malocclusion varies between 24% to 39% (11, 324, 329).

The cause of skeletal Cl II malocclusion might be maxillary protrusion, mandibular retrusion, or both. McNamara reported mandibular retrusion as the most common characteristic of all Cl II malocclusions rather than maxillary prognathism (206). Consequently, advancement of mandible is the main goal in the treatment of the mandibular retrusion cases.

Repositioning of the mandible is called functional jaw orthopedics (206) and removable or fixed functional appliances are used to advance the mandible (40, 244, 378).

Norman W. Kingsley first (1879) used forward positioning of the mandible in orthodontic treatment. His removable plate might be considered the prototype of functional appliances (179). Various types of functional appliances have been used to treat patients since then.

In 1909, at the International Dental Congress in Berlin, Emil Herbst (144) introduced a fixed pin and tube appliance to posture the mandible forward. The appliance kept the mandible in a continuous protruded position both during jaw closure and when the teeth were not in occlusion. Herbst claimed that condylar growth could be stimulated by his method of treatment, but no real proof could be presented.

In 1979, Hans Pancherz reintroduced the Herbst appliance and called attention to the possibilities of stimulating mandibular growth by means of this appliance (244).

It has gained increased popularity worldwide and various types of fixed functional appliances have been developed since that time (74, 88, 168, 204, 305, 310).

Pancherz et al (264) reported that, in functional appliance treatment, the position of the chin is affected by the following mechanisms: (1) mandibular condylar remodeling, (2) glenoid fossa remodeling, (3) condylar position changes within the fossa, and (4) mandibular autorotation.

The theoretical basis of functional treatment in general is the principle that a "new pattern of function," dictated by the appliance, leads to the development of a correspondingly "new morphologic pattern." The "new pattern of function" can refer to different functional components of the orofacial system – for example, the tongue, the lips, the facial and masticatory muscles, the ligaments, and the periosteum. Depending on the type of appliance, its proponent puts more emphasis on one of these different functional components. The "new morphologic pattern" includes a different arrangement of the teeth within the jaws, an improvement of the occlusion, and an altered relation of the jaws. It also includes changes in the amount and direction of growth of the jaws, and differences in the facial size and proportions (63).

Fixed functional appliances have the advantage of not relying on patient compliance because they are fixed in the mouth, thus always working, and they can be used concurrently with full fixed appliances. They apply expansion instead of compression forces and force vectors run along the y axis. The point of force application can be adjusted by segmental arches. Gentle continuous force 24 hours a day can be applied (335). One significant disadvantage is that they are more prone to breakage than their removable counterparts (381).

Forsus Fatigue Resistant Device (FRD) was introduced by Vogt in 2006 (374) which is an interarch push spring that produces about 200g of force when fully compressed. Since the Forsus springs are rarely fully compressed, however, they are comparable in force level to heavy Class II elastics. Unlike other push-spring appliances, such as the Herbst, the FRD can intrude the maxillary first molars and thus correct a Class II malocclusion without opening the bite.

The distal end of the FRD's push rod inserts into the telescoping cylinder, and a hook on the mesial end is crimped directly to the archwire near the canine or premolar brackets. The telescoping cylinder consists of inner and outer sliding tubes surrounded by an open-coil spring. An eyelet at the distal end of the cylinder is connected to the maxillary molar headgear tube with an L-pin.

In the literature, there are a few original articles which clear out the skeletal, dental and soft-tissue effects of this new developed fixed functional appliance (98, 173, 374).

In 2006, Vogt presented 3 cases which were treated by the FRD in his introduction study (374). He concluded that the FRD can be used instead of Class II elastics in mild cases and instead of Herbst appliances in severe cases. Forsus springs work best in patients with convex profiles, but they are indicated in any Class II patients except those with normal mandibles and protrusive maxillae, or with protrusive or overly large mandibles relative to the other cranial structures. He advised brackets with negative crown torque to be used to offset the spring forces that will tend to flare the mandibular incisors. Yet he did not mention any cephalometric variables of the patients and the number of patients was insufficient.

In 2007, El-Sheikh et al (98) performed a study about the FRD. Yet it was an in vitro study and they aimed to measure the mean force delivered at different amounts of deflection; to determine and compare the mean stiffness between loading and unloading; and to determine the resilience of the fatigue-resistant device springs. In short, this study was about the structural features of the FRD.

In 2008, Jones et al (173) evaluated the Forsus Fatigue Resistant Device as a compliance-free alternative to Class II elastics. They matched a sample of 34 (14 female, 20 male) consecutively treated nonextraction FRD patients (12.6 years of age) with a sample of 34 (14 female, 20 male) consecutively treated nonextraction Class II elastics patients (12.2 years of age) based on four pretreatment variables (ANB, L1-GoMe, SN-GoMe, and treatment duration). Pretreatment and posttreatment cephalometric radiographs were compared. In this study, only four variables were evaluated. Also the comparison was made between pretreatment and

finishing cephalometric radiographs. No statistically significant differences were found in the treatment changes between the groups. There was a general trend for mesial movement of the maxilla, mandible, and dentition during treatment for both groups. The mandibular skeletal advancement and dental movements were greater than those in the maxilla, which accounted for the Class II correction. Lower incisor proclination was evident in both groups. Vertically, the maxillary and mandibular molars erupted during treatment in both groups, while lower incisors proclined. With the exception of lower molar mesial movements and total molar correction, which were significantly greater in the Forsus group, there were no statistically significant group differences in the treatment changes. They pointed out that additional treatment might mask or negate some changes.

In 2009, short-term effects of the FRD L-Pin Module have been part of a thesis project at the Department of Orthodontics at the Yeditepe University (125). 15 young female or male patients between 13 and 17 years of age with a Class II malocclusion who underwent FRD therapy were compared with a control group consisting of 12 patients in the period of same skeletal age. The appliance was kept in the mouth till Class I relation was achieved. Lateral cephalograms and study models were obtained after the leveling phase and at time of the removal of the appliances in the treatment group and in the beginning and after 6 months in the control group. TPA was applied all patients. 0,022'' slot brackets were used and FRD was applied after passing 0,019×0,025'' stainless steel wires. According to results, no growth restriction in the maxilla was observed. Vertical dimension remained stable. Uprighting and extrusion in the upper incisors and proclination and intrusion in the lower incisors were noted. Occlusal plane was rotated in the clockwise direction. Overjet and overbite was reduced. An improvement in the soft-tissue profile was achieved.

In this study, since there were only a few published studies about FRD, we aimed to evaluate skeletal, dental and soft-tissue effects of *Forsus™ Fatigue Resistant Device* in growing Class II Division 1 individuals.

7.2. Discussion of Material and Method

Based on selection criteria, 30 patients were included to our study. 25 patients (16 males, 9 females) comprised the sample while 5 of 30 patients were excluded from the study due to lack of cooperation.

Sex distribution was not taken into consideration while the sample was selected. Buschang et al (59) indicated that at the age of 15 years, the cumulative mandibular length may be 2 mm shorter in girls with Class II malocclusions. This has also been suggested by Harris (135), although several reports found no difference (207, 348). Aelbers and Dermaut pointed out that although Buschang (59, 60), Bishara (39), and Carter (67) claim that mandibular growth is clearly gender related, obvious differences in response to orthopedic therapy in girls and boys were not clearly established in the publications, except from the studies of Luder (197, 198) and Jacobson (162) who did suggest some difference in response between girls and boys. Orgun (243) in his doctorate thesis stated that there is no significant difference between genders in both study and control groups about the treatment efficiency of Jasper Jumper in skeletal Cl II patients. In none of the published Forsus studies males and females were evaluated separately (10, 125, 140, 173, 175). Considering that the response to orthodontic therapy in girls and boys were not clearly established in the publications and in majority of the studies, gender was not taken into consideration in our study, and we evaluated both the males and the females together.

Inclusion criteria were:

- Skeletal Class II and dental Class II Division 1 malocclusion,
- Normal or mildly prognathic maxilla,
- Retrognathic mandible,
- Maximal pubertal growth not yet reached,
- Normal or low angle growth pattern,
- Permanent dentition,
- Minimum crowding in the dental arches.

Exclusion criteria were:

- Syndromic condition,
- Significant dental or skeletal asymmetry,
- Skeletal openbite characteristics,
- Temporomandibular joint dysfunction,
- Previous growth modification therapy,
- Gingival recession,
- Lack of cooperation.

These criteria are in accordance with the criteria of other investigators who apply fixed functional appliances (31, 61, 125, 175, 229, 243).

In our study, patients who have normal or slightly prognathic maxilla and retrognathic mandible with normal or low angle growth pattern were included. These skeletal features were also suggested in other fixed functional treatment studies (175, 229, 243).

According to Bishara (35), ideal circumstance for treatment with a functional appliance, in addition to the mandibular deficiency and normal maxillary development, is a normal or mildly decreased face height because, theoretically, most of these appliances encourage mandibular posterior dental eruption.

Pancherz (249) defines the ideal patient for treatment with the Herbst appliance having retrognathic mandible and normal or reduced lower face height. Besides, in a retrospective study, Ruf and Pancherz (316) compared the sagittal dental and skeletal effects contributing to Cl II correction in subjects with small or large pretreatment mandibular plane angles and the study showed that dental and skeletal changes contributing to Cl II correction are independent of the vertical jaw base relationship. Thus, a hyperdivergent jaw base relationship did not affect the treatment response unfavorably.

Petrovic (285) demonstrated that the growth rate, i.e., the potential responsiveness of the individual subject to FJO aimed to stimulate growth at the mandibular condyle, is significantly greater in the presence of anterior growth

rotation of the mandible than in the presence of posterior growth rotation of the mandible.

Schiavoni et al (332) reported that the Herbst appliance attached to bands do not significantly modify the vertical growth pattern of the normohypodivergent patients; and in hyperdivergent patients, the use of a Herbst appliance attached to acrylic splints in conjunction with the use of a high-pull headgear allows a better control of the vertical dimension.

Headgear effect which means restriction of maxillary growth of fixed functional appliances was reported in the literature (82, 83, 168, 218, 229, 247). Accordingly, we did not exclude patients with slight maxillary prognathism.

We evaluated patients according to skeletal age as assessed by a radiographic examination of the hand-wrist instead of chronological age. Grave and Brown (124) state that well-defined indicators of physiologic maturity provide a more reliable basis than chronological age for assessing growth potential in orthodontic practice. They revealed that indicators of developmental status, determined from carpal radiographs, are particularly useful as diagnostic aids to determine the most appropriate time and method for orthodontic treatment. In a review, Flores-Mir et al (105) pointed out that many studies have shown an association between peak velocity of facial growth and peak velocity of statural growth during puberty. Accordingly, in most of the functional treatment studies, timing of the treatment was established according to hand-wrist radiographs (185, 229, 247). In the FRD study of Günay (125) skeletal age was evaluated according to cervical vertebral maturation index.

In this study, hand-wrist radiographs were taken and interpreted according to the system developed by Fishman (102) in order to assess the skeletal ages of the sample. Fishman developed this system for assessment of skeletal maturation on the basis of 11 discrete ''skeletal maturity indicators (SMI)'' covering the entire period of adolescent development. The indicators provide identification of progressive maturation events and are located on six anatomic sites on the thumb, third finger, fifth finger, and radius. He provided graphs and tables to estimate an individual's

relative growth rate and percentage of total adolescent growth completed. These values are independent of chronological age.

The timing for functional appliance treatment remains a controversial clinical issue despite the considerable volume of literature on this topic. The main goal of therapy with functional appliances is to induce supplementary lengthening of the mandible by stimulating increased growth at the condylar cartilage (35, 162, 244, 264). Franchi et al (109) stated that the effectiveness of functional treatment of mandibular growth deficiency strongly depends on the biologic responsiveness of the condylar cartilage, which in turn depends on the growth rate of the mandible. It is well documented that the growth rate of the human mandible is not constant throughout development. A peak in mandibular growth velocity (pubertal growth spurt) has been described in many previous cephalometric studies (156, 230).

Clinical research has demonstrated that the greatest effects of functional appliances take place when the mandibular growth peak is included in the treatment period (15, 201, 287).

After the classical studies by Petrovic et al (287) and Petrovic and Stutzmann (286) the positive correlation between mandibular growth potential and mandibular responsiveness to FJO has been clearly established.

Hagg and Pancherz found that sagittal growth at the condyle in patients treated with the Herbst appliance at the pubertal growth peak was twice that observed in patients treated 3 years before or 3 years after the peak (127). In contrast, in 2000, Pancherz (253) suggested to revise the above concept in skeletal Class II therapy using age as a decisive factor when choosing between a growth adaptive or a surgical approach. He claims that growth in the TMJ region can continue for many years after the age of 20 years or can be reactivated at this later age.

Franchi and Baccetti (107) implies that, significantly greater effects of functional jaw orthopedics have to be expected when treatment is carried out at the peak in mandibular growth as detected by a reliable indicator of skeletal maturity when compared to the outcomes of treatment performed before or after the growth spurt.

Konik et al (182) found that proclination of the lower incisors (anchorage loss) in late treated (after pubertal growth) subjects is larger than in early treated subjects.

Considering the common idea about the timing of functional appliance treatment, we decided to deliver the appliance at the pubertal growth peak. Since the preparation of the patients for appliance delivery would take at least 6 months, patients who have not reached pubertal growth spurt were included to the study.

All of the initial records including intraoral-extraoral photographs, dental casts, panoramic, lateral cephalogram, posterior-anterior and hand-wrist radiographs were taken before the treatment (T0).

After the evaluation of dental casts, if there was any need for expansion, RPE with banded hyrax was applied and left in the mouth until the end of T2 in order to control upper molar width. 5 out of 25 patients (3 males, 2 females) were applied Hyrax in our study. In clinical applications of Herbst appliance, Pancherz recommended to solder a rapid palatal expansion screw to the premolar and molar bands or to the cast splint when maxillary expansion is required and the maxillary expansion is accomplished simultaneously with the Herbst appliance treatment (249, 252). In this type of Herbst appliance design, Hyrax is used as an anchorage unit. Similarly, we kept the Hyrax in the mouth to the end of Forsus treatment in order to control upper molar width and as an additional anchorage unit.

A 1.0 mm stainless steel transpalatal arch (TPA) was placed in the beginning to the rest of the patients for the same reason. If there was any molar rotation it was also corrected by activating TPA before the leveling and alignment phase. No transpalatal arches are used in the Edgewise Bioprogressive Herbst Appliance design of Dischinger so that the first permanent molars can rotate as the Class II relationship is corrected (91). However, according to McNamara et al (210), the incorporation of a Hyrax-type expansion screw or a transpalatal arch in the maxillary appliance adds rigidity to the appliance and minimizes the possibility of loosening. Jasper and McNamara suggests use of a transpalatal arch in those instances in which distal maxillary molar movement is to be minimized and mandibular adaptations are to be maximized. If maxillary dentoalveolar movement is desired, they do not incorporate

a transpalatal arch into the appliance system (168). Blackwood reported the expansion of the upper molars if heavy constricted maxillary archwires and/or transpalatal bars are not used as a usual result of Jasper Jumper (43). Use of a transpalatal arch was recommended by many fixed functional appliance studies (83, 229, 335). From the FRD studies, only Günay (125) used TPA.

On the other hand, Küçükkeleş et al (185) reported that the TPA may not be beneficial in situations where the upper is too narrow relative to the forward-positioned mandible. To counteract the maxillary expansion effect of the Jasper Jumper appliance, they formed the upper arch narrowly, and buccal root torque was incorporated in the posterior region. Similarly, Karaçay et al (175) incorporated buccal root torque in order to control transverse expansion of maxillary first molars in a Forsus and Jasper Jumper comparison study. But, they observed some expansion in the upper arch with both appliances and came to the conclusion that if the expansion effect is needed to be controlled, more precautions, such as inserting a transpalatal arch, should be considered.

We placed a 1.0 mm lingual arch attached to the first molars in the lower jaw in all patients in order to maintain lower arch perimeter. In the banded Herbst design, Pancherz introduced two main systems: partial anchorage and total anchorage (249). For partial anchorage, in the mandibular dental arch the bands of the first premolars are connected with a half-round (1,5 x 0.75 mm) or a round (1 mm) lingual archwire touching the lingual surfaces of the anterior teeth (247, 249, 252). For total anchorage, in the mandibular dental arch, bands are cemented on the first molars and connected to the lingual archwire which is extended distally (249, 252). Additionally, a premolar-to-premolar labial rectangular archwire attached to brackets on the anterior teeth can be used (261). We planned to place a lingual arch extending between first molars and touching the lingual surfaces of the anterior teeth serving as a total anchorage unit.

Blackwood (43) stated that the use of a transpalatal arch and fixed lower lingual arch is mandatory in patients with mixed dentitions whose premolars have not yet erupted so as to control potential unfavorable side effects produced by the Jasper Jumper (e.g., molar and incisor tipping and flaring).

The use of a fixed lower lingual arch is encouraged strongly in some reports of fixed functional appliances (168, 204, 380). However, the use of lingual arch was not reported in a large number of reports (82, 83, 185, 229).

In some of the studies, palatal root torque was incorporated in the maxillary archwire in order to prevent retroclination of the upper incisors (117) and labial root torque was incorporated in the mandibular archwire or lower incisor brackets with lingual crown torque incorporated into the slot were used to counteract the tendency for labial incisor tipping (83, 168, 310, 350). In our first preliminary cases, we incorporated 5 to 10 degrees of palatal root torque in the maxillary archwire in order to overcome the retroclination effect of FRD and 10 to 15 degrees of labial root torque in the mandibular archwire in order to overcome the proclination effect. But then, we observed excessive proclination in the upper incisors and it was possible to visualize the lower incisor roots through the buccal cortical bone. So, we assumed that it would be risky to push the lower incisors forward as a result of FRD application. We could have caused thinning or loss of marginal alveolar bone and create recession in the long term. We decided not to incorporate any additional positive torque to the upper incisors or negative torque to the lower incisors.

In none of the Forsus studies the use of lingual arch was reported (10, 125, 140, 173, 175, 374).

Alignment and leveling procedures started in every patient with a 0,018 slot Roth Prescription. After the leveling, 0,017-inch x 0,025-inch stainless steel archwires were engaged on the upper and lower arches just before the insertion of FRD. Both archwires were cinched back to prevent slippage and the lower teeth were laced between the first bicuspids to prevent space opening. In other Forsus studies, Karaçay et al (175) followed the same procedure. Different from our study, they incorporated buccal root torque to the maxillary archwire to control the transverse expansion of maxillary first molars. In a case report, Ross et al (308) used the same prescription. They inserted the FRD after the engagement of 0,016 x 0,022-inch stainless steel archwires. 0,017-inch x 0,025-inch stainless steel archwires were placed one month later when they made an activation by inserting a split crimp on

the push rod. Günay (125) used 0,022 slot straightwire braces in his FRD study and inserted the FRD after the engagement of 0,019 x 0.025-inch SS wires.

Similarly, thick and rectangular archwires were engaged and cinched back in other fixed functional studies (83, 168, 185, 229).

While delivering the FRD, it is important to choose appropriate push rod size. In some cases, we noticed that if one side is more Class II than the other side, the size of the rod in that side is smaller than the other side according to the Forsus™ Device Gauge. We thought that if we deliver the rods according to the gauge, the dental asymmetry would become more intense. So, we delivered the smaller size to the both sides in the first visit and activated or changed to the bigger size in other visits if needed.

After the delivery of FRD, patients were seen in monthly evaluation visits. At the first visit no activation was done. At the second visit, if there is any need for activation, it was performed by crimping one split ring bushing on push rod distal of stopper by compressing the spring as needed. If another activation was needed, no other split ring bushing was put; the push rod was changed with one size larger rod. In some cases, Class I relation is achieved in one side while the other side is still Class II. In those cases, activation was done only in the Class II side. At the other visits when Class I relation was achieved no activation was performed and the device was kept in the mouth for one more month for overcorrection.

In the introduction report of FRD, Vogt (374) stated that when the correct size is chosen the device delivers 200g of force. To keep the force level around 200g, the device should be activated by adding a crimpable stop. According to him, in a full Class II case, the Forsus springs should be continued until the incisors are edge-to-edge. If the Class II relationship is a half-cusp or less, it should not be corrected past a Class I position.

In a case report, Ross et al (308) performed the first activation one month after the insertion by adding a split crimp and the second activation by adding another split crimp in the next appointment. Günay (125) observed patients in monthly visits and performed activation once in 8 weeks. Karaçay et al (175) observed the patients

at 3-week intervals and they only stated that they activated the Forsus and Jasper Jumper appliances as needed.

The activation procedure was not discussed in any of other Forsus studies (10, 140, 173).

In the Herbst studies, Küçükkeleş and Erverdi (184) and Windmiller (386) performed the activation 3 months after the insertion. In the Jasper Jumper studies, Jasper and McNamara (168) and Weiland and Bantleon (379) performed the activation 2-3 months after the insertion. Cope et al (82) activated the appliance once in five weeks, while Küçükkeleş et al (185) activated once in 6 weeks. Covell et al (83) observed the patients at 4-week intervals and they activated the appliance as needed. Nalbantgil et al (229) observed patients at 4-week intervals and performed the activation once in 8 weeks.

Patients maintained the FRD for an average 6 months 2 days ± 2 months 16 days which is in accordance with the other Forsus studies (10, 125, 175, 308, 374) except the study of Heinig and Göz (140) in which the appliance was used over a period of 4 months. Time differences might exist because of the reason that some investigators keep the appliance in the mouth after achieving Class I relationship for overcorrection or retention purposes and some do not.

When Class I relation was achieved we kept the device in the mouth for one more month with no activation for overcorrection and retention. After achieving Class I or Super Class I molar and canine relation the FRD was removed. The patients were instructed to wear intermaxillary Class II elastics for a few month periods in order to maintain the Class II correction and allow a proper interdigitation of the posterior occlusion. In the studies of Günay (125), Karaçay et al (175) and Jones et al (173) treatments were carried out with Class II elastics after the appliance removal. In the study in which the FRD was used unilaterally, Ross et al (308) completed the final arch coordination and detailing with the same archwires and light Class II elastics.

As it is very difficult to overcorrect occlusal relationships with a flexible module, it was advised to retain the achieved sagittal occlusal relationships with light

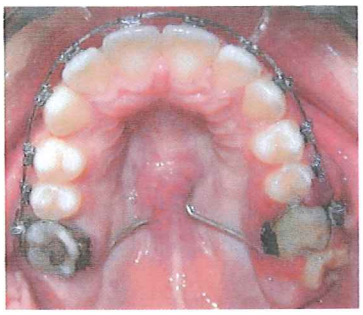
Class II elastics during ongoing fixed appliance therapy after removing the Jasper Jumpers (272). Orgun (243) and Nalbantgil et al (229) delivered Class II elastics for retention purpose in the finishing phase in their Jasper Jumper studies. Stucki and Ingervall (351) retained most of the patients with Class II elastics after removal of the Jasper Jumper. In a case report of Weiland and Droschl (380) full time Class II elastics were used to consolidate the achieved occlusal relationship.

Campbell (61) treated patients with another functional appliance -TFBC- for an average 3-month period and after removal of the appliance he instructed the patients to wear Class II elastics for a 3-month period.

In Herbst appliance therapy, it is advised to overcorrect occlusal relationships to an end-to-end incisor position. In the following 6 months, the occlusion settles (133). In the long term, relapse seems to be related to unstable occlusion. Therefore, it is recommended to retain the achieved occlusal relationships for at least 2 years with an activator (133). Since we settled the occlusion with elastics and achieved a good interdigitation we did not need to give activator to our finished patients.

In our study, when we deliver Class II elastics for retention after the removal of the FRD we did not remove the TPA and lingual arch or change the archwires. We removed the TPA and lingual arch and inserted rectangular twistoflex archwires when the occlusion is settled with up and down elastics and allowed a proper interdigitation of the posterior occlusion at the end of treatment.

In most of our cases, TPA came close to the palate because of the intrusion effect of the FRD on the upper molars. In some of these cases, TPA was even embedded into the palatal mucosa as complication (Picture 21). So, TPA should be constructed at least 3 mm away from the palatal mucosa.



Picture 21: TPA embedded into the palatal mucosa as complication.

In all of our cases, after the removal of the appliance we observed that lingual arches do not touch to the lower incisors and placed in an upward position (Picture 22). We think that this is because of the intrusion and proclination of lower incisors, but also, because of the clockwise rotation of the lower anterior region more than the lower posterior region.



Picture 22: Lingual arch in an upward position after the removal of the FRD.

We also faced some other problems during FRD treatment. In some of our cases the push rods disengaged from the cylinder. It might be because of that the push rods were too short and when the patient opened wide, they were disengaged or patient opened his/her mouth more than normal (374). In a few cases, lower canine brackets were debonded. It might be because of that the push rods were too long increasing the load on the canine brackets to the point that they debond (374). In some of the patients lower premolar brackets were also debonded together with the lower canine brackets. One of our patients broke the lower canine and first premolar brackets at the same time and two times. The patient explained that the push rod rotated into the bite and when he bit the brackets were broken.

The problem that we faced most frequently was fracture of L-pin. This was also reported in the case report of Ross et al (308). When L-pin was fractured the spring module comes out. Patients usually bring the spring module. In this situation we placed a new pin to the same module. According to our personal experience, after cinching the L-pin it should not be opened and cinched again. Otherwise, the L-pin is tired and the possibility for fracture increases. In some of the cases the telescoping cylinder was deformed and we placed a new telescoping cylinder It is recommended that while inserting the FRD, if patient bites on spring assembly, L-pin should be adjusted with a buccal offset (http://solutions.3m.com/wps/portal/3M/en_US/orthodontics/Unitek/solutions/classII/Forsus/), (Picture 6A). In our study, this offset was performed only 3 of the patients. This offset should not be exaggerated in order not to cause soft-tissue irritation inside the cheek which we faced in one of our patients that we made an offset.

Severe or slight soft-tissue irritations inside the cheek were observed in most of our patients. Upper molar tube was the most affected area. The second was the spring module area. The third but the most severe irritations were observed in the corner of the mouth where the hook of the push rod is placed. The most severe irritations occurred in patients who lie on their cheeks. So, patients were instructed not to lie on their cheeks in the beginning of the treatment. If severe irritation was observed in a patient, the appliance was removed and he/she was instructed to use mouthwash. After the recovery, the appliance was inserted again.

All of the patients were treated by the same doctor. By limiting the sample to one practitioner performing all the treatments, variation in treatment technique was minimized.

From the 25 patients, three sets of lateral cephalograms and hand-wrist radiograms were taken: initial (T1), before FRD insertion (T2), and after the removal of the appliance (T3). In the Herbst studies the cephalograms are usually taken before the insertion and just after the removal (182, 244, 250).

In the study of Stromeyer et al (350) with Eureka Spring, the cephalograms were obtained at the start of orthodontic treatment, at insertion of ES, and at removal of

the ES in accordance with our study. From Jasper Jumper studies, Küçükkeleş et al (185) took the cephalograms with the same procedure while the other investigators took before the insertion and after the removal (82, 83, 229, 351, 379). On the other hand, Covell et al (83) took the cephalograms before and after active edgewise orthodontic treatment. Similarly, Jones et al (173) took the cephalograms before and after active treatment in the study that they compared the FRD with Class II elastics. In the other Forsus studies Karaçay et al (175), Heinig and Göz (140) and Günay (125) took the lateral cephalograms before attachment and just after removal of the appliance.

All cephalograms of each patient were traced manually on acetate paper at the same time by one examiner to minimize any method error. Where right and left structures were identified, the midline of the two was used. Using stable anatomic structures, the three tracings were superimposed to distinguish growth/ displacement from dental movements. The anterior cranial base and cranial structures were superimposed to evaluate the total changes that occurred during FRD therapy. Following superimpositioning, the sella-nasion minus 7° horizontal reference line (RL1) and vertical reference line (RL2) drawn perpendicular to horizontal reference line from S point were transferred from the T0 to the T1 and T2 tracings. Using sella for registration, vertical linear measurements were done vertical to RL1; horizontal linear measurements were done vertical to RL2. Positive values represent downward or forward movement; negative values represent upward or backward movement.

The reference lines we used in our study were also used by in previous investigations (101, 301, 356, 363). Moreover, in the Forsus study of Günay (125) and in the Jasper Jumper studies of Cope et al (82) and Nalbantgil et al (229), the same reference lines were used. Küçükkeleş et al (185) established the reference plane according to *An Atlas of Craniofacial Growth* in which the perpendicular to a constructed horizontal line, 5,6° to SN plane, is taken as reference plane.

In some of the studies (83, 140, 175, 351, 379), the analysis of linear changes are made according to the method of Pancherz (248) in which a reference grid consisting of the occlusal line (OL) and the occlusal line perpendicular (OLp) is drawn on the tracing of the first headfilm and this grid is transferred to the other films by

superimposing on the sella-nasion line at sella. In our study, we did not use the method of Pancherz. Because, there were double images in most of the initial cephalograms and the occlusal line was difficult to define correctly.

In this study, 25 cephalometric landmarks were identified from which 43 cephalometric measurements were made and skeletal, dental and soft-tissue changes were evaluated on the cephalograms. In other Forsus studies, Günay (125) used 24 cephalometric landmarks and 36 cephalometric measurements. Karaçay et al (175) evaluated the changes on 13 cephalometric measurements. Jones et al (173) used 15 landmarks and the radiographs were analyzed using the pitchfork analysis (PFA).

In most of the functional appliance studies, the cephalometric changes were compared with an untreated control group (10, 82, 125, 175, 185, 229). Bolton standards were also used as control parameters in some studies (264, 336, 379). We compared the treatment changes between T0 and T1 with the changes between T1 and T2. We did not use a control group mostly because of ethical concerns. On the other hand, considering that the patients in FRD group continued growing during leveling stage, we thought it would be rational to use this period of treatment as control stage. We also thought that it would be more valuable to use growth changes of the same group of patients as controls for homogeneity of groups. This method was also used in some Cl III studies (217, 237). Ngan et al (237) evaluated the lateral cephalometric radiographs of 20 consecutively treated Class III patients by protraction headgear. For each patient, the first lateral cephalogram was taken 6 months before the initiation of headgear treatment (To), and the second radiograph at the start of treatment (T1). Therefore (T1 - To) represented 6 months of growth with no treatment. A third radiograph was taken 6 months after start of treatment (T2). In this way, (T2 – T1) - (T1 - To) represented the effect the result of appliance therapy alone and each subject served as his/her own control. Similarly, in the study of Vaughn et al (372), they aimed to quantify the effects of maxillary protraction with or without palatal expansion. Forty-six children aged 5 to 10 years were randomly assigned to 1 of 3 groups: Patients in group A were treated with palatal expansion with facemask therapy. Patients in group B were treated with passive palatal

appliances with facemask therapy. Patients in group C were observed only for at least 12 months and then randomly assigned to group A or B.

In the scientific investigations, to be able to use parametric tests the number of subjects has to be at least 30. If the sample consists less than 30 subjects, non-parametric tests are used (354). Since we have included 25 patients in our study, non-parametric tests were used. Statistical calculations were performed with NCSS 2007 program for Windows. Besides standard descriptive statistical calculations (mean and standard deviation), treatment group repeated measures of ANOVA was used to determine the differences in measurement at each time point. When $p < 0.05$, student Newman Keuls multiple comparisons tests were used for pair wise comparisons. Mann Whitney-U test (MW) was used in the comparison of treatment changes. Intraclass correlation coefficient was used reliability of measurements. Statistical significance level was established at $p < 0.05$.

To evaluate intraobserver measurement error in cephalometric tracings, 5 patients were selected at random and 3 lateral cephalograms of each patient were hand-traced again by the same observer. The reliability of the measurements was statistically evaluated by calculating the intraclass correlation coefficient and intraobserver measurement correspondence. The results were evaluated within a 95% confidence interval (354) (Table 4-6).

7.3. Discussion of Results

7.3.1. Discussion of Skeletal Changes

7.3.1.1. Discussion of Sagittal Skeletal Changes

When the treatment changes between T0 and T1 were compared with the changes between T1 and T2, statistically significant changes were observed in the 4 of 20 sagittal skeletal parameters (Table 13).

In the T0-T1, SNA angle decreased 0,16°±1,38° which is statistically insignificant. In the T1-T2, significant decrease of 1,32°±1,77° was observed in this angle. When the changes between T0-T1 and T1-T2 were compared, decrease at the SNA angle was statistically significant, showing the FRD was effective in restraining the forward growth of the maxilla. This finding is in accordance with the study of Karaçay et al (175). Heinig and Göz (140) reported that the SNA angle remained virtually constant during treatment with the Forsus spring while Günay (125) found an insignificant increase. Our finding is also in accordance with the Jasper Jumper study of Cope et al (82), who described this restriction as 'the headgear effect'. In the other Jumper studies, Küçükkeleş et al (185), Covell et al (83), Nalbantgil et al (229) and Stucki and Ingervall (351) also found a decrease at the SNA angle while Weiland and Bantleon (379) reported only limited skeletal effect on the maxilla. They claimed that part of the change occurring in the location of the A-point may be a reflection of the retrusion of the upper incisors during therapy and this may lead to a limited effect of the JJ on the normal sagittal development of the maxilla. In the Herbst studies, Pancherz and other investigators showed that Herbst appliance has a restraining effect on the maxillary growth, as shown by the decrease in the SNA angle during treatment (131, 133, 242, 244, 249, 260, 261). In contrast, Pancherz found a slight increase in the SNA angle during Herbst treatment and an additional increase was also recorded in the long-term posttreatment period (133, 250). In the MPA study of Siqueira et al (343) the SNA angle remained constant.

Another parameter which shows the sagittal position of maxilla is A-RL2. In our study, a significant increase of 0,68±1,44mm in the T0-T1 and a significant decrease of 0,92±2mm in the T1-T2 were observed in this value. The difference between T0-

T1 and T1-T2 was statistically significant indicating the maxillary restriction effect of the FRD. The finding of Günay (125) contradicts with our study. He found an insignificant increase in this value. He implied that this increase might be because of the retrusion of the upper incisors shifting the A-point anteriorly during therapy. Karaçay et al (175) and Heinig and Göz (140) used a reference line according to the method of Pancherz and this distance did not change in neither of the studies. In the Jasper Jumper studies, Küçükkeleş et al (185), Nalbantgil et al (229), Cope et al (82) found posterior displacement of A-point while Covell (83) and Stucki and Ingervall (351) and Weiland and Bantleon (379) reported no change. In the Herbst studies, posterior displacement of A-point was reported (249) while an anterior displacement was also reported (133, 247, 260, 261). However, when comparing the skeletal changes during treatment with those occurring in untreated controls, maxillary growth inhibition was reported in all studies.

SNB angle decreased 0,16°±1,18° which is statistically insignificant in the T0-T1, while an insignificant increase of 0,28°±1,34° was observed in the T1-T2. When the changes between T0-T1 and T1-T2 were compared, increase in the SNB angle was statistically insignificant indicating that the FRD did not have a stimulating effect on sagittal mandibular growth. This finding is in accordance with the study of Günay (125) while contradicting with the studies of Heinig and Göz (140) and Karaçay et al (175) who found an increase at the SNB angle. Considering the Jasper Jumper studies, our finding is in accordance with Cope et al (82), Nalbantgil et al (229), Küçükkeleş et al (185) and Covell et al (83) who did not found any stimulation effect on the mandibular growth while contradicting with Stucki and Ingervall (350) and Weiland and Bantleon (379) who found an increase in the SNB angle showing a stimulation effect of the JJ on the mandibular growth. In the Herbst studies, the increase in sagittal mandibular growth was evident by the increase in the SNB angle (131, 242, 244, 249, 250, 260, 261). This contradiction between the studies may be related to several factors such as age, variance of the sample groups, different appliances used and different treatment mechanics. Based on results from patients treated with the Herbst appliance, Pancherz suggested that the younger the patient, the greater the potential for stimulation of mandibular growth (244). On the other hand, in the present study, the mean patient age was younger than in the

Karaçay et al (175), Heinig and Göz (140) studies who found an increase in mandibular growth opposing this contention. Moreover, among the Jasper Jumper studies, the sample of Stucki and Ingervall (351) who reported mandibular growth stimulation was older than the other studies.

One of the parameters showing the sagittal position of the mandibular bony base is Pg-RL2. We found an insignificant increase of 0,28±2,64mm in the T0-T1 and a significant increase of 1±1,66mm in the T1-T2 in this value. The difference between T0-T1 and T1-T2 was statistically insignificant indicating that there was no change in the position of pogonion and mandibular length during the FRD therapy. This insignificant increase is in accordance with the study of Günay (125) in which he measured the distance between B-point and RL2. Different from our study, Karaçay et al (175) and Heinig and Göz (140) found a significant increase in Pg-OLP value. From the Jasper Jumper studies, Pg showed posterior displacement in the study of Cope et al (82), while Stucki and Ingervall (351) and Weiland and Bantleon (379) reported an increase in Pg-OLP. Küçükkeleş et al (185) reported a significant increase at the B-point to reference line distance while Nalbantgil et al (229) found an insignificant increase at the B-RL2. Considering the results from patients treated with the Herbst appliance, Pancherz reported an increase at the Pg-OLP in many studies (247, 249, 316).

The parameter showing the sagittal position change of the condyle is Ar-RL2. In our study, insignificant increase of 0,4±1,66mm and 0,32±1,35mm were observed in the T0-T1 and T1-T2, respectively. The difference between T0-T1 and T1-T2 was statistically insignificant showing that there was no extra growth in the condyle and the mandible during FRD therapy. This finding is in accordance with the finding of Heinig and Göz (140) who found an insignificant decrease in Ar-OLP distance. In the Jasper Jumper studies, Cope et al (82) reported forward movement of the condyle in the JJ group and backward movement for the control group while Stucki and Ingervall (351) and Weiland and Bantleon (379) found no change. In the Herbst studies, a significant effect on sagittal condylar growth was reported (259, 276, 278). Pancherz and Hagg reported that the maximum condylar growth was observed in subjects around the maximum pubertal growth (259). On the other hand, even though

all of the subjects in our study were in maximum pubertal growth period we did not find any condylar growth.

Another parameter showing the sagittal position of the mandible is mandibular length which refers to sum of Pg-RL2 and Ar-RL2. An insignificant increase of 0,68±2,93mm in this value in the T0-T1 was observed while a significant increase of 1,32±2,08 was observed in the T1-T2. The difference between T0-T1 and T1-T2 was statistically insignificant revealing that the mandibular length remains constant in the FRD therapy. Our finding is in accordance with the finding of Heinig and Göz (140) who found an insignificant increase in the length of the mandible during the Forsus therapy. On the other hand, Weiland and Bantleon (379) reported a significant increase in this value. An increase in the mandibular length was also detected in the studies with Herbst appliance (247, 249, 316).

Ar-Pg distance which is a linear measurement showing the total mandibular length increased 1,92±2,27mm in the T0-T1 and 2,04±1,95mm in the T1-T2 which are statistically significant. The difference between T0-T1 and T1-T2 is statistically insignificant supporting our other findings that the FRD did not affect the mandibular growth. This finding is in accordance with the study of Günay (125). Similarly, Karaçay et al (175) reported an increase in Co-Gn distance. In the Jasper Jumper studies, Nalbantgil et al (229) found an insignificant increase in the treatment group. Küçükkeleş et al (185) reported a significant increase in both the control and treatment groups at the Ar-Pg distance and they concluded that the Pg might have moved forward as a result of the remodeling processes in the articular fossa area. In agreement with our study, they found a significant increase during the leveling stage and it was attributed to the backward movement of articulare during mandibular posterior rotation, caused by the extruded molars during the leveling. Different from our study, the mandibular length increased more during Jasper Jumper study than could be expected from normal growth. Covell et al (83) reported no change in the control and treatment groups during Jasper Jumper therapy. An increase in Ar-Pg distance was also reported in some Herbst studies (316, 319).

The mandibular bony base was measured with Pg-RL2 distance in our study and in most of other studies. But, this measurement might change according to the

rotation of the mandible. Therefore, we also measured the distance between Go and Gn in order to reveal the real change in the mandibular bony base. This distance showed statistically significant increase of 0.96±2,21mm and 1,2±1,98mm in the T0-T1 and T1-T2, respectively. The difference between T0-T1 and T1-T2 is statistically insignificant indicating that there is no extra growth in the mandibular bony base during FRD therapy.

SL is a linear measurement showing the sagittal position of the Pg point. This distance increased 0,04±2,19mm and 0,4±2,57mm which are statistically insignificant in the T0-T1 and T1-T2, respectively. The difference between T0-T1 and T1-T2 was statistically insignificant supporting our other findings that FRD has no effect on mandibular sagittal position. In accordance with our study, Günay (125), Küçükkeleş et al (185) and Nalbantgil et al (229) found no significant change in SL distance.

SE is a linear measurement showing the sagittal position of the condyle. This distance increased 0,68±2,14mm and 0,12±1,59mm which are statistically insignificant in the T0-T1 and T1-T2, respectively. The difference between T0-T1 and T1-T2 was statistically insignificant supporting our finding that there was no extra growth in the condyle and the mandible during FRD therapy. Similarly, Günay (125), Küçükkeleş et al (185) and Nalbantgil et al (229) found no significant change in SE distance.

ANB angle which defines the severity of skeletal Cl II relationship remained stable in the T0-T1 while a significant decrease of 1,6°±1,71° was observed in the T1-T2. The difference between T0-T1 and T1-T2 was statistically significant indicating that the FRD therapy has some effect on correction of skeletal Cl II relationship. This correction is mostly because of the maxillary restriction effect as it was reported in the discussion of the SNA angle, but also because of the very little effect on the mandibular growth as it was defined in the discussion of the SNB angle. Our finding is in accordance with Karaçay et al (175) who found a significant decrease and with Heinig and Göz (140) who found an insignificant decrease in this angle. A reduction in the ANB angle was also reported in the JJ studies of Covell et al (83), Küçükkeleş et al (185), Nalbantgil et al (229), Stucki and Ingervall (351) and

Weiland and Bantleon (379). Considering the Herbst studies, a decrease in ANB angle was reported in many studies (247, 249, 316, 319).

N-A-Pg is an angular measurement which shows the skeletal convexity. This angle showed an insignificant increase of 1,64°±4,64° in the T0-T1 and a significant increase of 1,96°±3,27° in the T1-T2. The difference between T0-T1 and T1-T2 was not statistically significant pointing out that the FRD therapy did not improve the skeletal profile. This finding is in accordance with the finding of Günay (125). Different from our study, Nalbantgil et al (229) found a significant increase in N-A-Pg angle in their JJ study. This angle changes according to the Pg point. In some cases Pg point might show extra growth even there is no change in the position of B point or Pg point might not move forward in spite of forward movement of B point. Therefore, it should be pointed out that the skeletal convexity is mostly affected by the growth of Pg point and the Pg point might grow apart from the mandibular bony base.

Considering all of the sagittal skeletal changes, the only significant change was backward relocation of the A-point indicating that the appliance had a skeletal restrictive effect on the maxilla. No significant change was observed in any of the parameters which show the sagittal skeletal position of the mandible. Accordingly, it can be concluded that the FRD therapy did not stimulate the sagittal growth of the mandible.

7.3.1.2. Discussion of Vertical Skeletal Changes

SN/PP is an angular measurement which shows the vertical inclination changes of the maxilla. This angle increased 0,32°±1,6° in the T0-T1 and 0,32°±2,16° in the T1-T2, being insignificant for both periods. The difference between T0-T1 and T1-T2 was statistically insignificant revealing that the maxilla did not make any rotation during the FRD therapy. Our finding is in accordance with the findings of Günay (125) and Karaçay et al (175). Moreover, SN/PP angle remained unchanged in the JJ studies of Covell et al (83), Nalbantgil et al (229), Stucki and Ingervall (351) and Weiland and Bantleon (379). Küçükkeleş et al (185) reported a significant increase in the treatment group, but this increase was not significant when comparing with the

control group. Likewise, Pancherz reported that the inclination of the maxilla was unchanged during the Herbst therapy even though slight clockwise rotation was observed in the treatment group (244, 249, 250). Hansen et al (133) reported a decrease in the SN/PP angle in patients treated with the Herbst appliance after the maximum pubertal growth. On the other hand, Pancherz and Anehus-Pancherz (257) reported that the palatal plane tipped significantly downward during the whole examination period and this was about twice what was seen in the Bolton control group.

SN/MP is an angular measurement which shows the vertical inclination changes of the mandible. This angle showed an insignificant increase of 0,28°±2,07° in the T0-T1 and a significant increase of 0,96°±2,17° in the T1-T2. When the changes between T0-T1 and T1-T2 were compared, the difference was statistically insignificant showing that the mandible did not make a clockwise rotation during the FRD therapy. Our finding is in accordance with the findings of Günay (125), Karaçay et al (175) and Heinig and Göz (140). Similarly, in the JJ studies of Covell et al (83), Nalbantgil et al (229) and Weiland and Bantleon (379) the inclination of mandible remained stable. In agreement with our study, Cope et al (82) and Küçükkeleş et al (185) who found a clockwise rotation in the mandible during the JJ therapy reported that the mandibular plane remained relatively stable. On the other hand, in the study of Stucki and Ingervall (351) the inclination of the mandible decreased during treatment and they attributed this decrease to the effect of normal growth rotating the mandible anteriorly in most cases. Considering the effect of the Herbst appliance on the mandibular plane angle, the majority of the investigators found an increase during treatment (244, 249, 250, 260, 369) while some observed a decrease (126, 133). In the long-term, Ruf and Pancherz found that the Herbst appliance did not have a significant effect on the mandibular plane angle (315).

PP/MP angle is an angular measurement which shows the vertical jaw relationship between the maxilla and the mandible. This angle showed an insignificant decrease of 0,16°±2,41° in the T0-T1 and an insignificant increase of 0,08°±2,16° in the T1-T2. The difference between T0-T1 and T1–T2 was statistically insignificant showing that the anterior face height remained stable during the FRD

therapy. Our finding is in accordance with Karaçay et al (175) and Heinig and Göz (140). On the other hand, Stucki and Ingervall (351) reported a decrease in the vertical jaw relationship during JJ therapy which was attributed to the anterior rotation of the mandible through growth. Pancherz reported an increase in this angle in some of the Herbst appliance studies contradicting with our results (244, 249). In the contrary, Pancherz also reported no change and even decrease in the PP/MP angle during the Herbst therapy and a significant decrease in the long-term (250).

ANSMe/NMe is a rational linear measurement which shows the changes in the anterior face height. This ratio decreased 0,004±0,013% in the T0-T1 and increased 0,005±0,016% in the T1-T2 which are both statistically insignificant. The difference between T0-T1 and T1-T2 was statistically significant indicating that the lower face height shows a little increase during the FRD therapy. Although PP/MP angle did not show any significant change during the therapy, insignificant increase of this angle in the T1-T2 is in accordance with this finding. Günay (125) found an insignificant increase in this ratio. Karaçay et al (175) reported that the significant posterior rotation of the mandible elongated the anterior facial height because of the lower anterior face. This lower anterior face elongation is in agreement with our study. Covell et al (83), Stucki and Ingervall (351) and Nalbantgil et al (229) reported a slight reduction in lower face height during the JJ treatment contradicting with our results. Nalbantgil et al (229) attributed this decrease to the sample having a normal or low-angle growth pattern. Stucki and Ingervall (351) additionally stated that the anterior face height was larger in the younger group than in the older group at all three recordings, i.e. before and after active treatment and at the end of observation. Küçükkeleş et al (185) reported no change in the anterior face height during the JJ therapy, but they found a significant increase during leveling which was attributed to the extrusion of the posterior teeth. In the Herbst studies, an increase in the anterior lower facial height was reported (57, 244, 249). Hagg et al (126) and Nelson et al (234) observed an increase of the anterior lower facial height during Herbst treatment, which remained unchanged during the retention period.

Jarabak is a rational linear measurement which shows the changes in the posterior and anterior face heights. This ratio showed an insignificant increase of

0,002±0,021% in the T0-T1 and an insignificant decrease of 0,001±0,016% in the T1-T2. The difference between T0-T1 and T1-T2 was statistically insignificant indicating that the FRD therapy did not change the anterior face height. This finding is in accordance with Günay (125), Heinig and Göz (140) and Nalbantgil et al (229). Karaçay et al (175) found increase in both posterior and anterior facial heights, but they did not measure the Jarabak. In the Herbst studies of Paulsen et al (278) and Sidhu et al (340), both the anterior and posterior facial heights increased during treatment and they stated that this increase resulted in a mandibular translation without causing unfavorable rotation.

Gonial ratio is another rational linear measurement which shows the vertical position changes in the mandibular plane. This ratio showed an insignificant decrease of 0,013±0,0033% in the T0-T1 and an insignificant decrease of 0,001±0,032% in the T1-T2. The difference between T0-T1 and T1-T2 was statistically insignificant showing that the mandibular plane did not make any significant rotation during the FRD therapy. Our finding is in accordance with Günay (125), Heinig and Göz (140) and Nalbantgil et al (229). Küçükkeleş et al (185) found no change in the gonial ratio during the JJ therapy, but they found a significant decrease during leveling which could also be attributed to the extrusion of the posterior teeth and mandibular clockwise rotation accordingly.

Ar-Go distance is a linear measurement which shows the changes in the ramus height. This distance showed a significant increase of 1,36±2,4mm in the T0-T1 and an insignificant increase of 0,88±2,3mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically insignificant showing that the ramus height remained stable during the FRD therapy. This finding is in accordance with the JJ study of Covell et al (83).

A-RL1 is a linear measurement which shows the vertical inclination changes of the maxilla. This distance showed a significant increase of 0,92±1,71mm in the T0-T1 and a significant increase of 1,28±2,17mm in the T1-T2. The difference between T0-T1 and T1-T2 was statistically insignificant supporting our finding that the maxilla did not make any rotation during the FRD therapy. Our finding is in accordance with Günay (125) and Nalbantgil et al (229). Cope et al (82) reported a

vertical drop for A point of the JJ group and they attributed this drop to the retroclination of upper incisors.

Considering all of the vertical skeletal changes, mandibular plane and palatal plane remained relatively stable. The only significant vertical change was the little increase in the lower anterior face height during the therapy which can be attributed to the slight posterior rotation of the mandible.

7.3.2. Discussion of Dental Changes

When the treatment changes between T0 and T1 were compared with the changes between T1 and T2, statistically significant changes were observed in the 13 of 16 dental parameters (Table 14).

SN/OP is an angular measurement which shows the vertical inclination change in the occlusal plane. This angle showed a significant decrease of 2,12°±3,64° in the T0-T1 and a significant increase of 4,64°±5,21° in the T1-T2. The difference between T0-T1 and T1-T2 was statistically significant indicating that the occlusal plane rotates in the clockwise direction during the FRD therapy. The decrease in the T0-T1 might occur because of the lower premolar extrusion during leveling. Extrusion of upper incisors and distal tipping of upper molars, and intrusion and proclination of lower incisors and mesial tipping of lower molars all point to a clockwise rotation of the occlusal plane during the FRD therapy. In accordance with our study, Günay (125), Karaçay et al (175), Jones et al (173) and Heinig and Göz (140) reported a clockwise rotation in the occlusal plane in terms of bite opening. Cope et al (82), Covell et al (83), Küçükkeleş et al (185), and Weiland and Bantleon (379), all reported similar effects on the occlusal plane in their JJ studies. Similarly, in the majority of the Herbst studies, a clockwise rotation on the occlusal plane during treatment was reported mainly because of the distalization and intrusion of the maxillary first molars (212, 242, 249, 250, 257, 260, 386).

OP/MP is an angular measurement which shows the changes between the occlusal plane and the mandibular plane. This angle showed a significant increase of 3,24°±4,74° in the T0-T1 and a significant decrease of 4,88°±3,32° in the T1-T2. The difference between T0-T1 and T1-T2 was statistically significant supporting our

finding that the occlusal plane rotated in clockwise manner during the FRD therapy. An increase in the T0-T1 was observed in terms of premolar extrusion during leveling as mentioned before. Our finding is in agreement with the JJ study of Küçükkeleş et al (185) who found a significant decrease in the OP/MP angle during the therapy. On the other hand, they found no change in this angle during leveling contradicting with our study. This contradiction may be related to differences in treatment mechanics. Different from our protocol, they started treatment by intruding lower incisors in most of the cases.

PP/OP is an angular measurement which shows the changes between the occlusal plane and the palatal plane. This angle showed a significant decrease of 3°±3,67° in the T0-T1 and a significant increase of 4,12°±3,62° in the T1-T2. The difference between T0-T1 and T1-T2 was statistically significant supporting our finding that the occlusal plane rotated in clockwise manner during the FRD therapy. The significant decrease in the T0-T1 also supports our finding that the occlusal plane rotates in counterclockwise manner in terms of spee correction due to lower premolar extrusion during leveling. Our finding is similar to JJ study of Küçükkeleş et al (185), who found a significant increase in the PP/OP angle during the therapy. Different from our study, this angle remained stable during leveling contradicting with our study.

Evaluating the changes in the parameters which are related to the occlusal plane, it should be considered that the occlusal planes were difficult to define in most of the cephalograms because of double images. All of the occlusal planes were traced by centering the double images.

U1/SN is an angular measurement which shows the sagittal inclination changes of the upper incisors. This angle showed insignificant decrease of 0,72°±8,12° and 2,2°±7,05° in the T0-T1 and T1-T2, respectively. The difference between T0-T1 and T1-T2 was statistically insignificant showing that the upper incisor inclinations remained stable during the FRD therapy. Our finding contradicts those reported by Günay (125), Karaçay et al (175) and Heinig and Göz (140), where significant palatal tipping was observed on the upper centrals. Moreover, palatal tipping of upper centrals were also observed in the JJ studies of Cope et al (82), Covell et al

(83), Küçükkeleş et al (185), Nalbantgil et al (229) and Weiland and Bantleon (379). In the contrary, in the FRD study of Jones et al (173) proclination of upper incisors was reported. But, different from all other studies mentioned, in this study the finishing cephalogram was taken at the end of active phase orthodontic treatment. Therefore, additional orthodontic treatment may mask the effects of the FRD. Regarding the effect of the Herbst appliance on the maxillary incisors, a retroclination was evident at the end of the treatment phase (57, 212, 242, 250, 260), which was attributed to the pull of the transseptal fibers due to molar distalization or the altered position of the lower lip. The contradiction of our study with the other studies may be related to exaggerated incorporation of lingual root torque bending in some of our cases before the insertion of the FRD. On the other hand, there are also some Herbst studies where the investigators found no significant differences in the incisor position (244, 247, 369).

IMPA is an angular measurement which shows the sagittal inclination changes of the lower incisors. This angle showed an insignificant increase of 0,28°±5,11° in the T0-T1 and a significant increase of 9,04°±3,92° in the T1-T2. The difference between T0-T1 and T1-T2 was statistically significant revealing that the lower incisors are severely proclined -even though we used lingual arch as it was advised by Günay (125)- during the FRD therapy. Our finding is in accordance with the studies of Günay (125), Karaçay et al (175), Jones et al (173), and Heinig and Göz (140). Proclination in the mandibular incisors was also reported in the JJ studies of Cope et al (82), Covell et al (83), Küçükkeleş et al (185), Stucki and Ingervall (351), and Weiland and Bantleon (379). Nalbantgil et al (229) applied the JJ using sectional arches to prevent or minimize lower incisor proclination, but a statistically significant protrusion still occurred at the lower incisors. They suggested using of lower incisor brackets with negative torque values or having lingual crown torque at the lower anterior segment of the archwire to prevent this proclination. On the other hand, significant proclination was still observed in spite of labial root torque was incorporated in the mandibular archwire or lower incisor brackets with lingual crown torque incorporated into the slot were used in some fixed functional studies (83, 310, 350). Covell et al (83) states that 'taking into account the apparent dentoalveolar versus skeletal effects of the JJ appliance, it should be noted that although the

mandibular incisor angulation may not be ideal based on cephalometric means, the proclination may in part represent a necessary dentoalveolar compensation attendant to the persistent underlying skeletal base discrepancy'. With regard to Herbst studies, lower incisor proclination was reported in the majority of the studies (212, 242, 249, 250, 257, 260, 386). Konik et al (182) found that proclination of the lower incisors (anchorage loss) in late treated (after pubertal growth) subjects is larger than in early treated subjects.

Since the functional appliances lead to a significant incisor flaring, the effect of this flaring on gingival status is an important issue. In 1998, Ruf et al (314) reported a study about this subject. They surveyed 98 children for a total of 392 lower incisors, with a mean age of 12,8±1,4 years, treated with the Herbst appliance. In 380 of the surveyed teeth (97%), either no recession developed or preexisting recession remained unchanged during Herbst therapy. In only 12 teeth (3%) did recession develop or preexisting recession deteriorate during treatment. No interrelation was found between the amount of incisor proclination and the development of gingival recession. They concluded, orthodontic proclination of lower incisors in children and adolescents seems not to result in gingival recession.

Holdaway is a rationale linear measurement which shows the relation between the lower incisor tip and the Pg point. This ratio showed an insignificant increase of 0,12±1,48% in the T0-T1 and a significant increase of 3,28±1,31% in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant supporting our finding that the lower incisors severely proclined during the FRD therapy. Our finding is similar to that of Günay (125) where a significant increase in the L1-NB distance was observed. Moreover, increase in the L1-NB distance was also reported in the JJ studies of Covell et al (83), Küçükkeleş et al (185), and Nalbantgil et al (229).

U1-RL2 is a linear measurement which shows the sagittal position changes of upper central tips. This distance showed an insignificant decrease of 0,12±2,62mm in the T0-T1 and a significant decrease of 2±1,83mm in the T1-T2. The difference between T0-T1 and T1-T2 was statistically significant showing that the upper central incisors were distalized during the FRD therapy. This finding is in accordance with

Karaçay et al (175) and Heinig and Göz (140) who used the method of Pancherz for measuring upper incisor-vertical reference line distance. In the JJ studies of Stucki and Ingervall (351) and Weiland and Bantleon (379), Pancherz's method was used and similar results were observed. Küçükkeleş et al (185) and Nalbantgil et al (229) also reported that U1-RL distance decrease during the JJ therapy in agreement with our study. Considering our other finding that upper incisor inclinations remained stable during the therapy, we can say that upper incisors did not tip palatally, but bodily distalized during the FRD therapy.

U1-RL1 is a linear measurement which shows the vertical position changes of upper central tips. This distance showed an insignificant increase of 0,68±1,8mm in the T0-T1 and a significant increase of 2,36±2,06mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant showing that the upper incisors extrude during the FRD therapy. Our finding is in accordance with Günay (125), Karaçay et al (175) and Jones et al (173). Upper incisor extrusion was also reported in the JJ studies of Cope et al (82), Küçükkeleş et al (185), and Nalbantgil et al (229), while no vertical change was observed in the study of Covell et al (83). Regarding the Herbst studies, extrusion of upper incisors was observed at the end of treatment (57, 126) while no significant changes were found during the retention period (126).

L1-RL2 is a linear measurement which shows the sagittal position changes of lower central tips. This distance showed an insignificant increase of 0,52±1,9mm in the T0-T1 and a significant increase of 3,08±2,64mm in the T1-T2. The difference between T0-T1 and T1-T2 was statistically significant showing that the lower central incisors were mesialized during the FRD therapy. Our finding is in accordance with Karaçay et al (175) and Heinig and Göz (140). Mesial movement of lower incisors was also reported in the JJ studies of Küçükkeleş et al (185), Nalbantgil et al (229), Weiland and Bantleon (379) and Stucki and Ingervall (351). The increase in the L1-RL2 distance is in agreement with the increase in the IMPA in our study.

L1-RL1 is a linear measurement which shows the vertical position changes of lower central tips. This distance showed a significant increase of 2,16±2,73mm in the T0-T1 and a significant increase of 5,52±2,71mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant showing that the lower incisors

intrude during the FRD therapy. Our finding is in accordance with Karaçay et al (175) and Jones et al (173). Lower incisor intrusion was also reported in the JJ studies of Cope et al (82), Covell et al (83), Küçükkeleş et al (185), and Nalbantgil et al (229). Regarding the Herbst studies, intrusion of lower incisors which can be attributed to the proclination of these teeth during the therapy was reported (126, 212, 249, 334, 340).

U6-RL2 is a linear measurement which shows the sagittal position changes of upper first molars. This distance showed an insignificant increase of 0,76±2,57mm in the T0-T1 and an insignificant decrease of 0,96±2,51mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant showing that the upper molars tipped distally during the FRD therapy. Our finding is in accordance with Karaçay et al (175) and Heinig and Göz (140), while contradicts with the finding of Jones et al (173) who found mesialization in the upper molars. Different from other studies, since, Jones et al took the finishing radiograph at the end of active orthodontic treatment, mesial movement with growth and anchorage loss due to additional orthodontic treatment may mask or negate distal movements in this study. Distal movement of upper molars was also reported in the JJ studies of Cope et al (82), Covell et al (83), Küçükkeleş et al (185), Nalbantgil et al (229), Stucki and Ingervall (351) and Weiland and Bantleon (379). Regarding the influence of the Herbst appliance on the maxillary molars, a distal molar movement and a distal tipping during treatment was reported in the majority of the studies (212, 242, 247, 249, 250, 260). In the contrary, Burkhardt et al (57) reported a mesialization in the upper molars following Herbst treatment. They attribute this finding to the outgrowth of the mandible. They stated that the maxillary first molars must move anteriorly to the same extent that the mandibular first molars move anteriorly.

U6-RL1 is a linear measurement which shows the vertical position changes of upper first molars. This distance showed an insignificant increase of 1,24±3,15mm in the T0-T1 while remained stable in the T1-T2. The difference between T0-T1 and T1-T2 is statistically insignificant showing that the upper molars did not intrude during the FRD therapy. Since our sample consisted of growing individuals, intrusion effect of the appliance might be negated by growth. Our finding is in

agreement with the study of Günay (125) who found an insignificant intrusion in the upper molars. On the other hand, Karaçay et al (175) reported intrusion while Jones et al (173) reported extrusion. The contradictory finding of Jones et al can be attributed the method difference as mentioned before. An intrusion in the upper molars was also reported in the JJ studies of Cope et al (82), Covell et al (83), Küçükkeleş et al (185) and Nalbantgil et al (229). Considering the Herbst studies, it was observed that the maxillary first molars were intruded during the treatment period (125, 212, 249, 257, 334).

L6-RL2 is a linear measurement which shows the sagittal position changes of lower first molars. This distance showed an insignificant increase of 0,76±2,33mm in the T0-T1 and a significant increase of 3,64±2,33mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant showing that the lower molars tipped mesially during the FRD therapy. Our finding is in accordance with Karaçay et al (175), Jones et al (173) and Heinig and Göz (140). Mesial movement of the lower molars was also reported in the JJ studies of Cope et al (82), Covell et al (83), Küçükkeleş et al (185), Nalbantgil et al (229), Stucki and Ingervall (351), and Weiland and Bantleon (379). Mesial movement of the mandibular first molars was also reported in the Herbst studies, as a result of the anteriorly directed force of the Herbst appliance (57, 108, 247, 249, 259).

L6-RL1 is a linear measurement which shows the vertical position changes of lower first molars. This distance showed a significant increase of 1,52±3,12mm in the T0-T1 and a significant increase of 0,8±1,8mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically insignificant showing that the lower molars did not extrude during the FRD therapy. This finding is in accordance with our finding that upper molars did not intrude during the therapy. Different from our study, Karaçay et al (175) and Jones et al (173) reported extrusion of lower molars. Extrusion of the lower molars was also reported in the JJ studies of Cope et al (82), Covell et al (83), Küçükkeleş et al (185), and Nalbantgil et al (229). In the studies with Herbst appliance, extrusion of lower molars was detected (126, 212, 249, 257, 334). In our study, we found a clockwise rotation in the occlusal plane, but we did not find intrusion in the upper molars or extrusion in the lower molars. This refers to

significant anterior dentoalveolar downward movement during the therapy going along with extrusion of upper incisors and intrusion of lower incisors.

Evaluating the changes in the sagittal and vertical positions of the upper and lower molars, it should be remembered that double images were present in most of the lateral cephalograms sagittally and vertically causing these measurement errors. Even though all of the double images were centered while tracing, the results might be affected from this situation.

OJ is a linear measurement which shows the horizontal distance between upper and lower incisor tips. This distance showed an insignificant decrease of 0,52±2,49mm in the T0-T1 and a significant decrease of 5,12±3,07mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant revealing the reduction of overjet during the FRD therapy. A reduction in overjet was found in both the leveling and the FRD application stages. During leveling, the reduction was related to the incisor angulation changes, whereas during FRD therapy many factors led to the change, including the headgear effect of the appliance, distal movement of the upper incisors and the proclination of the lower incisors. Our finding is in accordance with the findings of Günay (125), Karaçay et al (175), Heinig and Göz (140) and Jones et al (173). A decrease in the overjet was also reported in the JJ studies of Cope et al (82), Covell et al (83), Küçükkeleş et al (185), Nalbantgil et al (229), Stucki and Ingervall (351), and Weiland and Bantleon (379). The study of Küçükkeleş et al (185) indicated that more than 80% of the reduction in overjet was dental. A reduction in the overjet was reported in the studies of the Herbst appliance (126, 212, 247, 249, 257, 259, 334). Pancherz and Haag (249), Pancherz (247), and Wieslander (383) reported overjet reduction with the Herbst appliance, but they stated the reduction in overjet to be mainly due to forward mandibular movement.

OB is a linear measurement which shows the vertical distance between upper and lower incisor tips. This distance showed a significant decrease of 1,6±2,45mm in the T0-T1 and a significant decrease of 3,16±2,04mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant revealing the reduction of overbite during the FRD therapy. The reduction during leveling might have happened because of the incisor movements whereas clockwise rotation of the

occlusal plane, intrusion and proclination of the lower incisors led to the change during FRD therapy. Our finding is in accordance with the findings of Günay (125), Karaçay et al (175), and Jones et al (173). A decrease in the overbite was also reported in the JJ studies of Cope et al (82), Covell et al (83), Küçükkeleş et al (185), Nalbantgil et al (229), and Stucki and Ingervall (351). After the Herbst therapy, it was reported that the incisal edge-to-edge relationship leaves the buccal segment out of occlusion, which contributes to the allowance of normal vertical tooth eruption and growth in the posterior segments (244, 247). Thus, a reduction in the overbite should be anticipated (244). After Herbst treatment the overbite was reduced (57, 244, 249, 334, 340).

The findings related to dentoalveolar structures showed that dentoalveolar changes were quite larger than the skeletal effects induced by the FRD. The upper and lower teeth were engaged in a thick and rectangular wire, forming one unit. As a result, when the distal and vertical directed force of the FRD caused upper molar distalization, the consequent effects on the upper anterior region were incisor elongation and retraction. Similarly, the mesial and vertical directed force of the FRD caused lower molar mesialization, and lower incisor intrusion and proclination. The overall result was a clockwise rotation of the occlusal plane. The reduction in overjet was mostly related to retraction in upper incisors, and the proclination of the lower incisors over and above headgear effect of the appliance. Overbite was also reduced due to clockwise rotation of the occlusal plane, and the intrusion and proclination of lower incisors.

We observed that the profiles were favorably improved after the FRD therapy especially in the cases who have low Holdaway values at the start of treatment. Accordingly, the prominent Pg should be considered as an inclusion criterion in fixed functional treatment approaches.

7.3.3. Discussion of Soft-tissue Changes

When the treatment changes between T0 and T1 were compared with the changes between T1 and T2, statistically significant changes were observed in the 4 of 7 dental parameters (Table 15).

Nasolabial angle is an angular measurement which shows the relation between the nose and the upper lip. This angle showed an insignificant decrease of 0,96°±4,57° in the T0-T1 and a significant increase of 3,48°±6,3° in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant showing the upper lip retraction during the FRD therapy. This finding might be attributed to upper incisor retraction during the therapy. Our finding is in agreement with the JJ study of Nalbantgil et al (229), while contradicts with the FRD study of Günay (125) who did not find any significant change in this angle. Retrusion of the upper lip was also reported in the Herbst studies (57, 258).

N'-Sn'-Pg' is another angular measurement which shows the changes in the soft-tissue convexity. This angle showed an insignificant decrease of 1,36°±3,33° in the T0-T1 and a significant increase of 2,48°±3,19° in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant showing that the soft-tissue convexity reduced during the FRD therapy. This finding conflicts with our finding that the skeletal convexity did not change during the therapy revealing that the improvement in the profile is achieved by the soft-tissue changes. In the Herbst studies, significant changes in the facial angles related to a soft-tissue Menton protrusion were reported (258, 319, 322).

The sagittal position changes of the upper lip according to E line are presented by Lab. Sup.-E line. This distance showed an insignificant increase of 0,08±1,55mm in the T0-T1 and a significant increase of 2,24±1,91mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant showing that the upper lip was retruded during the FRD therapy. Our finding is in accordance with the findings of Günay (125) and Nalbantgil et al (229). On the other hand, Flores-Mir et al (104) reported that the E plane is not a good reference plane to quantify changes in the lips

because simultaneous changes in the soft-tissue Pogonion or Pronasale could create the impression of lip changes that are really nonexistent.

The linear measurement of Lab. Inf.-E line shows the sagittal position changes of the lower lip according to E line. This distance showed an insignificant decrease of 0,04±2,15mm in the T0-T1 and an insignificant increase of 0,08±1,47mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically insignificant showing that the lower lip was not affected during the FRD therapy. This finding is in accordance with the study of Günay (125), while contradicting with the JJ study of Nalbantgil et al (229) who found forward movement of the lower lip.

One other linear measurement, Lab. Sup.-RL2, presents the sagittal position changes of the upper lip. This distance showed a significant increase of 1,76±1,83mm in the T0- T1 and a significant decrease of 1,12±1,9mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically significant revealing the retrusion of the upper lip during the FRD therapy. This finding is in accordance with our other findings that upper lip was retruded during the therapy. Since upper teeth moved labially during leveling, Lab. Sup.-RL2 increased in the T0-T1. Although the difference was not statistically significant in their study, Günay et al (125) reported that the FRD therapy leads to upper lip retraction. Our finding is in agreement with the JJ studies of Küçükkeleş et al (185) and Nalbantgil et al (229), while contradicting with the Forsus study of Karaçay et al (175) who did not find any change in the upper lip position.

The sagittal position changes of the lower lip are shown by Lab. Inf.-RL2. This distance showed a significant increase of 1,44±1,96mm in the T0-T1 and a significant increase of 1±2,1mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically insignificant showing that the lower lip is not affected during the FRD therapy. Because both lips are supported more significantly by the upper incisors as was reported by Flores-Mir et al (104), changes in the anteroposterior position of the upper incisors more significantly affect the lip position than do changes in the lower incisors. This might be the reason that lower lip position was not affected from the therapy in spite of severe mandibular incisor proclination. Our finding is in accordance with the finding of Günay (125) while contradicting with the

study of Karaçay et al (175) who reported a protrusion in the lower lip which was attributed to forward displacement of the mandible and protrusion of the mandibular incisors. Different from our study, Küçükkeleş et al (185) and Nalbantgil et al (229) also reported forward movement of lower lip during JJ therapy. Similar to our study, remaining of the lower lip was reported in the Herbst studies (57, 258). The reported lower incisor protrusion produced by the Herbst treatment did not appear to be associated with the protrusion of Labrale Inferius in these studies. The soft-tissue adaptability to hard tissue changes has been shown to be a complex, not linear association (176).

And the last parameter to mention is Pg'-RL2 which shows the sagittal position changes of the soft-tissue pogonion. This distance showed an insignificant increase of 0,8±2mm in the T0-T1 and a significant increase of 1,44±1,99mm in the T1-T2. The difference between T0-T1 and T1-T2 is statistically insignificant showing that the soft-tissue pogonion was not affected during the FRD therapy. This finding is in accordance with our skeletal finding that Pg-RL2 was not affected during the therapy. Different from our study, Karaçay et al (175) reported protrusion of soft-tissue pogonion during Forsus and JJ therapies. Forward movement of the pogonion was also found in the JJ study of Küçükkeleş et al (185). In the Herbst studies, consistently no change was reported to the soft-tissue Menton (258, 322).

Analysis of the soft-tissue changes showed that the retraction of upper incisors and upper lip position are interrelated. On the other hand, proclination of the lower incisors did not lead to a change in lower lip position. This might be because of the finding that the positions of both lips are supported more significantly by the upper incisors (104) as mentioned before. No significant changes were found for the soft-tissue Pogonion.

Even though upper lip retraction was the only significant change, the FRD therapy favorably improved the facial convexity. As the upper incisors retruded, the upper lip moved back and the lower lip was no longer captured behind the upper incisors. In addition, the proclined lower incisors supported the lower lip.

In most of the Class II cases who have very little or no growth left, surgery is indicated. Ruf and Pancherz (319,320) have shown that young adults with Class II malocclusions could be treated successfully with functional jaw orthopedics. Mandibular prognathism was increased and the skeletal and soft-tissue convexity was reduced. In another study (322), they compared Class II-adults treated successfully by either orthognathic surgery or dentofacial orthopedics. It was revealed that the hard and soft-tissue profile convexity was significantly reduced by both methods. They concluded that Herbst appliance therapy can be considered as an alternative to orthognathic surgery in borderline skeletal Class II adult patients. If, however, the patient's main wish is a greatly improved facial profile, orthognathic surgery is the better treatment alternative, they added. Similarly, Chaiyongsirisern et al (70) compared the treatment effects and long-term stability of the stepwise Herbst appliance and mandibular sagittal split osteotomy in skeletal Class II adult patients. All Herbst and surgery patients were treated successfully to Class I occlusal relationships. According to results, the surgery group showed larger changes. Yet, in terms of long-term stability, both groups achieved stable results, and no significant difference occurred over time. Also, Weiland and Droschl (380) used a Jasper Jumper in one of their cases who did not want surgery and received very satisfactory results.

Taking these into consideration this treatment method could be an alternative to orthognathic surgery in some borderline Class II cases. In addition, since we found that most of the correction was achieved by dentoalveolar changes, using age as a decisive factor can be revised when choosing a growth adaptive or a surgical approach. We suggest using FRD therapy in both adult and growing patients. Yet, *we observed that the profiles were more favorably improved in low angle cases with prominent Pogonions, this should be considered as an indication criterion for this protocol.*

8. CONCLUSIONS

In this study, we evaluated skeletal, dental and soft-tissue effects of *Forsus™ Fatigue Resistant Device* in growing Class II Division 1 individuals by comparing the changes in leveling phase (T0-T1) and Forsus application phase (T1-T2). The results demonstrated that:

1. The maxilla underwent limited posterior displacement.

2. Condylar growth and total mandibular length were not affected.

3. Mandible did rotate (clockwise) very slightly.

4. Maxilla did not make any rotation.

5. Upper incisors were retracted and extruded while the inclinations of these teeth remained stable.

6. Lower incisors were proclined and intruded.

7. Upper molars underwent significant posterior tipping.

8. Lower molars underwent significant anterior tipping.

9. Vertical positions of the upper and lower molars remained stable.

10. The occlusal plane rotated clockwise due to dentoalveolar changes.

11. Upper lip was retracted.

12. Overjet and overbite were reduced.

13. Class I or super Class I relationships were achieved in the molars and canines.

Because of its pronounced dentoalveolar effects, the Forsus™ Fatigue Resistant Device can successfully be used in nongrowing individuals. Low angle Class II cases

with prominent Pogonion –especially Class II Division 2 cases- who have dentoalveolar retrusion are the ideal candidates for this treatment protocol.

Finally, Forsus™ Fatigue Resistant Device is effective in treating Class II Division 1 malocclusion mostly through dentoalveolar changes. Follow-up studies are also necessary to establish the long-term stability of this appliance.

9. REFERENCES

1. Ahlgren J, Laurin C. (1976). Late results of activator-treatment: A cephalometric study. *Br J Orthod,* 3:181–187.

2. Aidar LAA, Dominguez GC, Abrahão M, Yamashita HK, Vigorito JW. (2009). Effects of Herbst appliance treatment on temporomandibular joint disc position and morphology: A prospective magnetic resonance imaging study. *Am J Orthod Dentofacial Orthop,* 136:412-24.

3. Almeida MR, Castanha Henriques JF, Almeida RR, Ursi W. (2002). Treatment effects produced by Fränkel appliance in patients with Class II, Division 1 malocclusion. *Angle Orthod,* 72:418-25.

4. Angle EH. (1899). Classification of malocclusion. *Dental Cosmos,* 41:248-264; 350-357.

5. Angle EH. (1907). Treatment of Malocclusion of the Teeth, 7th ed, S.S. White Dental Manufacturing, Philadelphia.

6. Andresen V. (1910). Beitrag zur retention. *Zahnartzl Orthop,* 3:121.

7. Andresen V. (1936). Über das sogenannte 'norwegische System der Funktions-Kieferorthopädie,' *Dtsch Zahnartzl Wochenschr,* 39:235.

8. Andresen V, Häupl K. (1936). *Funktionskieferorthopädie: die Grundlagen des 'norwegischen Systems,' e*d 2, H Meusser, Leipzig, Germany.

9. Andresen V, Häupl K, Petrik L. (1957). *Funktionskieferorthopädie,* ed 6, Johann Ambrosium Barth, Munich.

10. Arıcı S, Akan H, Yakubov K, Arıcı N. (2008). Effects of fixed functional appliance treatment on the temporomandibular joint. *Am J Orthod Dentofacial Orthop,* 133:809-14.

11. Arslan SG, Darı O, Atay MH. (2003). Son dört yılda kliniğimize başvuran hastalardaki ortodontik anomalilerin Angle sınıflamasına göre dağılımları: Retrospektif Çalışma. *Dicle Tıp Dergisi,* 30:31-35.

12. Auf der Maur HJ. (1980). Electromyographic recordings of the lateral pterygoid muscle in activator treatment of Class II Division I malocclusion cases. *Eur J Orthod,* 2:161-71.

13. Baccetti T, Franchi L, McNamara JA Jr, Tollaro I. (1997). Early dentofacial features of Class II malocclusion: A longitudinal study from the deciduous through the mixed dentition. *Am J Orthod Dentofacial Orthop*, 111(5):502-509.

14. Baccetti T, Franchi L, Stahl F. (2009). Comparison of 2 comprehensive Class II treatment protocols including the bonded Herbst and headgear appliances: A double-blind study of consecutively treated patients at puberty. *Am J Orthod Dentofacial Orthop,* 135:698.e1-698.e10.

15. Baccetti T, Franchi L, Toth LR, McNamara JA Jr. (2000). Treatment timing for Twin-block therapy. *Am J Orthod Dentofacial Orthop,* 118:159-170.

16. Bacon W, Eiller V, Hildwein M, Dubois G. (1992). The cranial base in subjects with dental and skeletal Class II. *Eur J Orthod*, 14:224-228.

17. Bakke M, Paulsen HU. (1989). Herbst treatment in late adolescence: Clinical, electromyographic, kinesiographic, and radiographic analysis of one case. *Eur J Orthod,* 11:397-407.

18. Baltromejus S, Ruf S, Pancherz H. (2002). Effective temporomandibular joint growth and chin position changes: Activator versus Herbst treatment. A cephalometric roentgenographic study. *Eur J Orthod,* 24:627–637.

19. Barnett GA, Higgins DW, Major PW, Flores-Mir C. (2008). Immediate skeletal and dentoalveolar effects of the Crown- or Banded Type Herbst appliance on Class II Division 1 malocclusion. *Angle Orthod*, 78:361-369.

20. Barton S, Cook PA. (1997). Predicting functional appliance treatment outcome in Class II malocclusions-a review. *Am J Orthod Dentofacial Orthop*, 112: 282-286.

21. Baume LJ. (1974). Uniform methods for the epidemiologic assessment of malocclusion: Results obtained with the World Health Organization standard methods (1962 and 1971) in South Pacific populations. *Am J Orthod Dentofacial Orthop,* 66:251-72.

22. Baumrind S, Korn EL, Isaacson RJ, West EE, Molthen R. (1983). Quantitive analysis of the orthodontic and orthopedic effects of maxillary traction. *Am J Orthod Dentofacial Orthop,* 84:384-98.

23. Baumrind S, Korn EL, Molthen R, West EE. (1981). Changes in mandibular dimensions associated with the use of force to retract the maxilla. *Am J Orthod Dentofacial Orthop,* 79:17-30.

24. Baumrind S, Korn EL, Molthen R, West EE. (1983). Changes in facial dimensions associated with use of forces to retract the maxilla. *Am J Orthod Dentofacial Orthop,* 84:384-98.

25. Baumrind S, Molthen R, Korn EL. (1978). Mandibular plane changes during maxillary retraction. *Am J Orthod Dentofacial Orthop,* 74:32.

26. Baumrind S, Molthen R, West EE, Miller D. (1978). Mandibular plane changes during maxillary retraction, part 2. *Am J Orthod Dentofacial Orthop,* 74:603-621.

27. Beattie JR, Paquette DE, Johnston LE. (1994). The functional impact of extraction and nonextraction treatments: A long-term comparison in patients with 'borderline', equally susceptible Class II malocclusions. *Am J Orthod Dentofacial Orthop*, 105:444-449.

28. Behrents RG. (1985). Growth of the aging craniofacial skeleton: Monograph 17, Craniofacial growth Series. Ann Arbor: Center for HumannGrowth and Development, The University of Michigan.

29. Bernstein L, Ulbrich WR, Gianelly A. (1977). Orthopedics versus orthodontics in Class II treatment: An implant study. *Am J Orthod Dentofacial Orthop,* 72:549-59.

30. Birkebaek L, Melsen B, Terp S. (1984). A laminagraphic study of the alterations in the temporo-mandibular joint following activator treatment. *Eur J Orthod,* 6:257–266.

31. Bishara SE. (1998). Mandibular changes in persons with untreated and treated Class II Division 1 malocclusion. *Am J Orthod Dentofacial Orthop*, 113(6):661-673.

32. Bishara SE. (2000). Facial and dental changes in adolescents and their clinical implications. *Angle Orthod,* 70(6):471-483.

33. Bishara SE. (2001). Textbook of Orthodontics. 1st ed, Saunders Company, Philadelphia, p.83

34. Bishara SE. (2001). Textbook of Orthodontics. 1st ed, Saunders Company, Philadelphia, p.103.

35. Bishara SE. (2001). Textbook of Orthodontics. 1st ed, Saunders Company, Philadelphia, p.326-366.

36. Bishara SE. (2001). Textbook of Orthodontics. 1st ed, Saunders Company, Philadelphia, p.83-85, p.324-374.

37. Bishara SE. (2006). Class II malocclusion: Diagnostic and clinical considerations with and without treatment. *Semin Orthod*, 12:11-24.

38. Bishara SE, Bayati P, Jakobsen JR. (1996). Longitudinal comparisons of dental arch changes in normal and untreated Class II, Division 1 subjects and their clinical implications. *Am J Orthod Dentofacial Orthop,* 110(5):483-489.

39. Bishara SE, Jamison JE, Peterson LC, De Kock WH. (1981). Longitudinal changes in standing height and mandibular parameters between the ages of 8 and 17 years. *Am J Orthod Dentofacial Orthop*, 80:115-35

40. Bishara SE, Ziaja RR. (1989). Functional appliances: A review. *Am J Orthod Dentofacial Orthop,* 95:250–258.

41. Björk A. (1955). Cranial base development. *Am J Orthod Dentofacial Orthop,* 41:198-255.

42. Björk A. (1969). Prediction of mandibular growth rotation. *Am J Orthod Dentofacial Orthop*, 55(6):585-599.

43. Blackwood HO. (1991). Clinical management with the Jasper Jumper. *J Clin Orthod*, 25:755-60

44. Blechman AM. (1985). Magnetic force systems in orthodontics: Clinical results of a pilot study. *Am J Orthod Dentofacial Orthop,* 87:201-210.

45. Boecler PR. (1989). Skeletal changes associated with extraoral appliance therapy: An evaluation of 200 consecutively treated cases. *Angle Orthod*, 59:263-70.

46. Boley JC, Pontier JP, Smith S, Fulbright M. (1998). Facial changes in extraction and nonextraction patients. *Angle Orthod*, 68:539-546

47. Bolmgren GA, Moshiri F. (1986). Bionator treatment in Class II, Division 1. *Angle Orthod,* 56:255–262.

48. Borzabadi-Farahani A, Borzabadi-Farahani A, Eslamipour F. (2009). Malocclusion and occlusal traits in an urban Iranian population. An epidemiological study of 11- to 14-year-old children. *Eur J Orthod*, 31:477-484.

49. Bowman SJ, Johnston LE. (2000). The esthetic impact of extraction and nonextraction treatments on caucasian patients. *Angle Orthod*, 70:3-10.

50. Braga GC, Machado GB. (2001). Eureka Spring for finishing correction of class II and improving anchorage. *R Dental Press Orthodon Orthop Facial,* 6:51-60.

51. Brezniak N, Arad A, Heller M, Dinbar A, Dinte A, Wasserstein A. (2002). Pathognomonic cephalometric characteristics of Angle Class II Division 2 malocclusion. *Angle Orthod,* 72(3):251–257.

52. Brin I, Tulloch JFC, Koroluk L, Philips C. (2003). External apical root resorption in Class II malocclusion: A retrospective review of 1- versus 2-phase treatment. *Am J Orthod Dentofacial Orthop*, 124:151-6.

53. Brodie AG. (1946). Facial patterns: A theme on variation. *Angle Orthod*, 16:75-87.

54. Brodie AG. (1952). Considerations of musculature in diagnosis, treatment and retention. *Am J Orthod Dentofacial Orthop,* 38:823-835.

55. Brodie AG. (1953). Muscular factors in the diagnosis and treatment of malocclusions. *Angle Orthod,* 23(2):71–77.

56. Brodie AG. (1965). Muscles, growth and the apical base. *Dent. Practit,.* 15:343-357,

57. Burkhardt DR, McNamara JA Jr, Baccetti T. (2003). Maxillary molar distalization or mandibular enhancement: A cephalometric comparison of comprehensive orthodontic treatment including the pendulum and the Herbst appliances. *Am J Orthod Dentofacial Orthop,* 123:108-116.

58. Buschang PH, Stroud J, Alexander RG. (1994). Differences in dental arch morphology among adult females with untreated Class I and Class II malocclusion. *Eur J Orthod,* 16:47-52.

59. Buschang PH, Tangway R, Demirjian A, La Palme L, Goldstein H. (1986). Sexual dimorphism in mandibular growth of 7 French-Canadian children to 10 years of age. *Am J Phys Anthropol,* 71:33-7.

60. Buschang PH, Tangway R, Demirjian A, La Palme L, Turkewicz J.(1988). Mathematical models of longitudinal mandibular growth for children with normal and untreated Class II, Division 1 malocclusion. *Eur J Orthod,* 10:227-34.

61. Campell E. (2003). A prospective clinical trial and mechanical analysis of a push type fixed intermaxillary Class II correction appliance. Master of Dental Science Thesis, University of Connecticut.

62. Carano A, Testa M. (1996). The Distal Jet for upper molar distalization. *J Clin Orthod*, 30:374-380.

63. Carels C, Van der Linden F. (1987). Concepts on functional appliances mode of action. *Am J Orthod Dentofacial Orthop,* 92:162-168.

64. Carlsson GE, Bergman R, Hedegard B. (1967). Changes in contour of the maxillary alveolar process under immediate dentures. A longitudinal clinical and x-ray cephalometric study covering 5 years. *Acta Odontol. Scand.*, 25:45-75.

65. Carlson DS, McNamara JA Jr, Jaul DH. (1978). Histological analysis of the growth of the mandibular condyle in the rhesus monkey (*Macaca mulata*). *Am J Anat,* 151:103-13.

66. Carmichael GJ, Banks PA, Chadwick SM. (1999). A modification to enable progressive advancement of the Twin Block appliance. *Br J Orthod,* 26:9–13

67. Carter NE. (1987). Dentofacial changes in untreated Class 1I Division 1 subjects. *Br J Orthod,* 14:225-34.

68. Cassidy KM, Harris EF, Tolley EA, Keim RG. (1998). Genetic influence on dental arch form in orthodontic patients. *Angle Orthod,* 68:445-454.

69. Chadwick SM, Aird JC, Taylor PJ, Bearn DR. (2001). Functional regulator treatment of Class II Division 1 malocclusions. *Eur J Orthod*, 23:495-505.

70. Chaiyongsirisern A, Rabie AB, Wong RWK. (2009). Stepwise advancement Herbst appliance versus mandibular sagittal split osteotomy. *Angle Orthod,* 79:1084–1094

71. Chung C, Wong WW. (2002). Craniofacial growth in untreated skeletal Class II subjects: A longitudinal study. *Am J Orthod Dentofacial Orthop*, 122:619-26.

72. Clark WJ. (1982). The twin block traction technique. *Eur J Orthod,* 4:129-138.

73. Clark WJ. (1988). The twin block traction technique: A functional orthopaedic appliance system. *Am J Orthod Dentofacial Orthop,* 93:1–18.

74. Coelho Filho CM. (1995). Mandibular protraction appliances for Class II treatment. *J Clin Orthod*, 29:319-336

75. Coelho Filho CM. (1997). Clinical application of the Mandibular protraction appliances. *J Clin Orthod*, 31:92-102.

76. Coelho Filho CM. (1998). The Mandibular protraction appliance N° 3. *J Clin Orthod*, 32:379-384.

77. Coelho Filho CM. (2001). The Mandibular protraction appliance IV. *J Clin Orthod,* 35:18-24.

78. Coelho Filho CM. (2002). Clinical application of the mandibular protraction appliance in upper lateral agenesy and in asymmetric cases. *Tex Dent J,* 119: 618-626.

79. Coelho Filho CM, White L. (2003). Treating adults with the Mandibular Protraction Appliance. *Orthodontic CYBER journal*, Available online at: www.oc-j.com/jan03/MPA2.htm

80. Cohlmia JT, Ghosh J, Sinha PK, Nanda RS, Currier GF. (1996). Tomographic assessment of temporomandibular joints in patients with malocclusion. *Angle Orthod*, 66:27-36.

81. Conley RS, Jernigan C. (2006). Soft tissue changes after upper premolar extraction in Class II camouflage therapy. *Angle Orthod*, 76:59-65.

82. Cope JB, Buschang PH, Cope DD, Parker J, Blackwood HO. (1994). Quantitative evaluation of craniofacial changes with Jasper Jumper therapy. *Angle Orthod*, 64:113–122.

83. Covell DA, Trammell DW, Boero RP, West R. (1999). A cephalometric study of Class II Division 1 malocclusions treated with the Jasper Jumper appliance. *Angle Orthod*, 69:311–320.

84. Cozza P, Baccetti T, Franchi L, De Toffol L, McNamara JA. (2006). Mandibular changes produced by functional appliances in Class II malocclusion: A systematic review. Am *J Orthod Dentofacial Orthop,* 129(5):599.e1-599.e12.

85. Craig CE. (1951). The skeletal patterns characteristic of Class I and Class II, Division I malocclusions in norma lateralis. *Angle Orthod,* 21(1):44–56

86. Creekmore TD, Radney LJ. (1983). Frankel appliance therapy: Orthopedic or orthodontic? *Am J Orthod Dentofacial Orthop*, 83:89-108.

87. Croft RS, Buschang PH, English JD, Meyer R. (1999). A cephalometric and tomographic evaluation of Herbst treatment in the mixed dentition. *Am J Orthod Dentofacial Orthop,* 116:435-443.

88. DeVincenzo JP. (1997). The Eureka Spring: A new interarch force delivery system. *J Clin Orthod,* 31:454-467.

89. DeVincenzo JP, Smith KD. (2001). Analysis of relapse following rapid class II correction with Eureka springs. *Eur J Orthod,* 23:449.

90. Dionne DG. Clinical Trial Report: Forsus™ Fatigue Resistant Device. *Orthodontic Perspectives,* 9(1):11-12. Available on at: www.3m.com/us/healthcare/unitek/pdfOP vol9No1.PDF.

91. Dischinger TG. (1989). Edgewise Bioprogressive Herbst Appliance. *J Clin Orthod*, 23:608-617.

92. Dischinger TG. (1995). Edgewise Herbst Appliance. *J Clin Orthod,* 29:738-742.

93. Dolce C, McGorray SP, Brazeau L, King GJ, Wheeler TT. (2007). Timing of Class II treatment: Skeletal changes comparing 1-phase and 2-phase treatment. *Am J Orthod Dentofacial Orthop,* 132:481-9.

94. Dolce C, Schader RE, McGorray SP, Wheeler TT. (2005). Centrographic analysis of 1-phase versus 2-phase treatment for Class II malocclusion. *Am J Orthod Dentofacial Orthop*, 128:195-200.

95. Drelich RC. (1948). A cephalometric study of untreated Class II, Division 1 malocclusion. *Angle Orthod,* 18(3):70–75.

96. Droschl H. (1984). Die fernröntgenwerte unbehandelter kinder zwischen dem 6. und 15. Lebensjahr. *Quintessenz,* p.68–103.

97. Eberhard H, Hirschfelder U. (1998). Treatment of Class II, Division 2 in the late growth period. *J Orofac Orthop,* 59:352-361.

98. El-Sheikh MM, Godfrey K, Manosudprasit M, Viwattanatipa N. (2007). Force-deflection characteristics of the fatigue-resistant device spring: an in vitro study. *World J Orthod*, 8: 30-36.

99. Enlow DH. (1996). Growth of the Mandible. In: Essentials of facial growth. Eds: Endow DE, Hans MG, WB Saunders, Philadelphia, p.57-78

100. Faltin K Jr, Faltin RM, Baccetti T, Franchi L, Ghiozzi B, McNamara JA Jr. (2003). Long-term effectiveness and treatment timing for Bionator therapy. *Angle Orthod,* 73(3):221-230.

101. Firouz M, Zernik J, Nanda R. (1992). Dental and orthopedic effects of high-pull headgear in treatment of Class II, Division 1 malocclusion. *Am J Orthod Dentofacial Orthop,* 102:197-205

102. Fishman LS. (1982). Radiographic evaluation of skeletal maturation. A clinically oriented method based on hand-wrist films. *Angle Orthod,* 52:88-112.

103. Flores-Mir C, Ayeh A, Goswani A, Charkhandeh S. (2007). Skeletal and dental changes in Class II Division 1 malocclusions treated with Splint-Type Herbst appliances. *Angle Orthod,* 77:376-381.

104. Flores-Mir C, Major MP, Major PW. Soft Tissue Changes with Fixed Functional Appliances in Class II Division 1. Angle Orthod 2006;76:712–720

105. Flores-Mir C, Nebbe B, Major PW. (2004). Use of skeletal maturation based on hand-wrist radiographic analysis as a predictor of facial growth: A systematic review. *Angle Orthod,* 74(1):118-24.

106. Fortini A, Lupoli M, Giuntoli F, Franchi L. (2004). Dentoskeletal effects induced by rapid molar distalization with the first class appliance. *Am J Orthod Dentofacial Orthop,* 125:697-705.

107. Franchi L, Baccetti T. (2006). Prediction of Individual Mandibular Changes Induced by Functional Jaw Orthopedics Followed by Fixed Appliances in Class II Patients. *Angle Orthod,* 76(6):950-54.

108. Franchi L, Baccetti T, McNamara JA Jr. (1999). Treatment and post-treatment effects of acrylic splint Herbst appliance therapy. *Am J Orthod Dentofacial Orthop,* 115:429-438.

109. Franchi L, Baccetti T, McNamara JA Jr. (2000). Mandibular growth as related to cervical vertebral maturation and body height. *Am J Orthod Dentofacial Orthop,* 118:335-340.

110. Frankel R. (1966). The theoretical concept underlying treatment with function correctors, *Trans Eur Orthod Soc,* p.233-250.

111. Frankel R. (1969). The treatment of Class II Division 1 malocclusion with functional correctors. *Am J Orthod Dentofacial Orthop,* 55:265- 275.

112. Frankel R. (1980). A functional approach to orofacial orthopaedics. *Br J Orthod*, 7:41-51.

113. Fränkel R. (1984). Concerning recent articles on Fränkel appliance therapy. *Am J Orthod Dentofacial Orthop,* 85(5):441-445.

114. Freeman CS, McNamara JA, Baccetti T, Franchi L, Graff TW. (2007). Treatment effects of the bionator and high-pull facebow combination followed by fixed appliances in patients with increased vertical dimensions. *Am J Orthod Dentofacial Orthop*, 131(2):184-195.

115. Fröhlich FJ. (1962). Changes in untreated Class II type malocclusions. *Angle Orthod,* 32(3):167–179.

116. Gábris K, Márton S, Madléna M. (2006). Prevalence of malocclusions in Hungarian adolescents. *Eur J Orthod*, 28: 467 - 470.

117. Gazivekili C. (2007). Mandibular Retrognatiye Bağlı Sınıf II Olgularda İskeletsel Ankraj Desteği İle Birlikte Kullanılan Jasper Jumper Apareyinin Etkilerinin Sefalometrik İncelemesi. Marmara Üniversitesi Sağlık Bilimleri Enstitüsü, Doktora Tezi, İstanbul, (Danışman: Prof. Dr. N Erverdi).

118. Gianelly AA, Cozzani M, Boffa J. (1991). Condylar position and maxillary first premolar extraction. *Am J Orthod Dentofacial Orthop*, 99:473-476.

119. Gianelly AA, Hughes HM, Wohlgemuth P, George G. (1988). Condylar position and extraction treatment. *Am J Orthod Dentofacial Orthop*, 93:201-205.

120. Gill D, Sharma A, Naini F, Jones S. (2005). The twin block appliance for the correction of Class II malocclusion. *Dent Update.* 32:158–160, 163–164, 167–168.

121. Goodman P, McKenna P. (1985). Modified Herbst appliance for the mixed dentition. *J Clin Orthod,* 19:811-814.

122. Graber TM, Rakosi T, Petrovic AG. (1985). Dentofacial orthopedics with functional appliances. Principles of functional appliances. St Louis, Mosby, p.68-91.

123. Graber TM, Rakosi T, Petrovic AG. (1997). Dentofacial orthopedics with functional appliances, 2nd ed, St Louis, Mosby.

124. Grave KC, Brown T. (1979). Carpal radiographs in orthodontic treatment. *Am J Orthod Dentofacial Orthop*, 75:27-45

125. Günay EA. (2009). Genç Erişkinlerde Uygulanan Forsus Apareyinin İskeletsel, Dişsel ve Yumuşak Dokular Üzerine Olan Etkilerinin Değerlendirilmesi. Yeditepe Üniversitesi Sağlık Bilimleri Enstitüsü, Doktora Tezi, İstanbul, (Danışman: Prof. Dr. T Arun).

126. Hagg U, Du X, Rabie AB. (2002). Initial and late treatment effects of headgear-Herbst appliance with mandibular step-by-step advancement. *Am J Orthod Dentofacial Orthop*, 122:477-485.

127. Hagg U, Pancherz H. (1988). Dentofacial orthopaedics in relation to chronological age, growth period and skeletal development: An analysis of 72 male patients with Class II Division 1 malocclusions treated with the Herbst appliance. *Eur J Orthod,* 10:169-176.

128. Hagg U, Tse EL, Rabie AB, Robinson W. (2002). A comparison of splinted and banded Herbst appliances: Treatment changes and complications. *Aust Orthod J,* 18:76-81.

129. Hamilton SD, Sinclair PM, Hamilton RH. (1987). A cephalometric, tomographic, and dental cast evaluation of Frankel therapy. *Am J Orthod Dentofacial Orthop*, 92:427-36.

130. Hansen K, Iemamnueisuk P, Pancherz H. (1995). Long-term effects of the Herbst appliance on the dental arches and arch relationships: A biometric study. *Br J Orthod,* 22:123-134.

131. Hansen K, Koutsonas TG, Pancherz H. (1997). Long-term effects of Herbst treatment on the mandibular incisor segment: A cephalometric and biometric investigation. *Am J Orthod Dentofacial Orthop,* 112: 92-103.

132. Hansen K, Pancherz H. (1992). Long-term effects of Herbst treatment in relation to normal growth development: A cephalometric study. *Eur J Orthod,* 14:285-295.

133. Hansen K, Pancherz H, Hagg U. (1991). Long term effects of the Herbst appliance in relation to the treatment growth period: A cephalometric study. *Eur J Orthod*, 13:471-81.

134. Hansen K, Pancherz H, Petersson A. (1990). Long term effects of the Herbst appliance on the craniomandibular system with special reference to the TMJ. *Eur J Orthod,* 12:244-253.

135. Harris JE. (1962). A cephalometric analysis of mandibular growth rate. *Am J Orthod Dentofacial Orthop*, 48:161-74,

136. Harris EF, Johnson MG. (1991). Heritability of craniometric and occlusal variables: A longitudinal sib analysis. *Am J Orthod Dentofacial Orthop,* 99:258-268.

137. Harrison JE, O'Brien KD, Worthington HV. (2007). Orthodontic treatment for prominent upper front teeth in children. The Cochrane Library, Issue 3. http://www.mrw.interscience.wiley.com/cochrane/clsysrev/articles/CD003452/ frame.html.

138. Harvold EP, Vargervik K. (1971). Morphogenetic response to activator treatment. *Am J Orthod Dentofacial Orthop,* 60:478–490.

139. Hashim HA. (1991). Analysis of activator treatment changes. *Aust Orthod J,* 12:100–104.

140. Heinig N, Göz G. (2001). Clinical application and effects of the Forsus™ spring, a study of a new Herbst hybrid. *J Orofac Orthop,* 62:436–450.

141. Hellsing G, Hollender LG, Carlsson GE, Johansson B. (1985). Temporomandibular joint adaptation to mandibular repositioning in adult occlusal rehabilitation. *J Craniomand Pract,* 3:273-9.

142. Helm S. (1968). Malocclusion in Danish children with adolescent dentition: An epidemiologic study. *Am J Orthod Dentofacial Orthop,* 54:352-366.

143. Henneberke M, Prahl-Andersen B. (1994). Cranial base growth for Dutch boys and girls: A multilevel approach. *Am J Orthod Dentofacial Orthop,* 106(5):503-512.

144. Herbst E. (1934). Dreissigjahrige erfahrungen mit dam retentions- scharnier. *Zahnärztliche Rundschau,* 43:1515-1524, 1563-1568, 1611-1616.

145. Hilgers JJ. (1992). The pendulum appliance for class II noncompliance therapy. *J Clin Orthod,* 26:706-714.

146. Hilgers JJ. (1998). Hyper efficient orthodontic treatment using tandem mechanics. *Semin Orthod,* 4:17-25.

147. Hinton RJ, McNamara JA Jr. (1984). Temporomandibular bone adaptation in response to protrusive function in juvenile and young adult rhesus monkeys (*Macaca mulatta*). *Eur J Orthod,* 6:155-74.

148. Hiyama S, Ono PT, Ishiwata Y, Kuroda T, McNamara JA Jr. (2000). Neuromuscular and skeletal adaptations following mandibular forward positioning induced by the Herbst appliance. *Angle Orthod,* 70:442-453.

149. Hoffelder LB, De Lima EMS, Martinelli FL, Bolognese AM. (2007). Soft-tissue changes during facial growth in skeletal Class II individuals. *Am J Orthod Dentofacial Orthop,* 131(4):490-495.

150. Hollender L, Ridell A. (1974). Radiography of the temporomandibular joint after oblique sliding osteotomy of the mandibular rami. *Scand J Dent Res,* 82:466-9.

151. Hotz RP. (1973). The changing pattern of European orthodontics. *Br J Orthod*, 1:4-8.

152. Howe RP. (1982). The bonded Herbst appliance. *J Clin Orthod,* 16: 663-667.

153. Howe RP. (1983). Updating the bonded Herbst appliance. *J Clin Orthod* 17: 122-124.

154. Howe RP, McNamara JA. (1983). Clinical management of the bonded Herbst appliance. *J Clin Orthod*, 17:456-463.

155. Hubbard GW, Nanda RS, Currier GF. (1994). A cephalometric evaluation of nonextraction cervical headgear treatment in Class II malocclusions. *Angle Orthod,* 64:359-70.

156. Hunter CJ. (1966). The Correlation of facial growth with body height and skeletal maturation at adolescence. *Angle Orthod,* 36:44–54.

157. Illing HM, Morris DO, Lee RT. (1998). A prospective evaluation of Bass, Bionator and Twinblock appliances. Part 1—the hard tissues. *Eur J Orthod,* 20:501-16.

158. Ingervall B, Bitsanis E. (1986). Function of masticatory muscles during the initial phase of activator treatment. *Eur J Orthod,* 8:172-84.

159. İşeri H, Solow B. (1990). Growth displacement of the maxilla in girls studied by the implant method. *Eur J Orthod,* 12:389 - 398.

160. Jacobs RM, Brodie AG. (1966). The Analysis of Perioral muscular accommodation in young subjects with malocclusion. *Angle Orthod,* 36(4):325–334.

161. Jakobsson SO. (1967). Cephalometric evaluation of treatment effect on Class II, Division 1 malocclusions. *Am J Orthod Dentofacial Orthop,* 53:446-57.

162. Jakobsson SO, Paulin G. (1990). The influence of activator treatment on skeletal growth in angle class II: 1 cases. A roentgenocephalometric study. *Eur J Orthod,* 12:174–184.

163. Janson G, Busato MCA, Henriques JFC, De Freitas MR, De Freitas LMA. (2006). Alignment stability in Class II malocclusion treated with 2- and 4-premolar extraction protocols. *Am J Orthod Dentofacial Orthop,* 130(2):189-195.

164. Janson G, Graciano JTA, Henriques JFC, De Freitas MR, Pinzan A, Pinzan-Vercelino CRM. (2006). Occlusal and cephalometric Class II Division 1 malocclusion severity in patients treated with and without extraction of 2 maxillary premolars. *Am J Orthod Dentofacial Orthop,* 129(6):759-767.

165. Janson M, Hasund A. (1981). Functional problems in orthodontic patients out of retention. *Eur J Orthod*, 3:173-179.

166. Janson G, Maria F, Barros SEC, De Freitas MR, Henriques JFC. (2006). Orthodontic treatment time in 2- and 4-premolar-extraction protocols. *Am J Orthod Dentofacial Orthop,* 129(5):666-671.

167. Jasper JJ. (1987). *The Jasper Jumper-a fixed functional appliance.* Sheboygan, Wisconsin: American Orthodontics.

168. Jasper JJ, McNamara JA. (1995). The correction of interarch malocclusions using a fixed force module. *Am J Orthod Dentofacial Orthop*, 108:641-650.

169. Jing Y, Chan-ling W, Dong-xu L, Jie G, Fan Z. (2006). Clinical effect of modified Forsus appliance to children with mandibular retrusion. West China Journal of Stomatology, 24: 246-249.

170. Johannsdottir B, Thorarinsson F, Thordarson A, Magnusson TE. (2005). Heritability of craniofacial characteristics between parents and offspring estimated from lateral cephalograms. 127(2):200-207.

171. Johnston LE Jr. (1996). Functional appliances: A mortgage on mandibular position. *Austral Orthod J,* 14:154-7.

172. Joner RD, White MJ. (1992). Rapid class II molar correction with an open-coil jig. *J Clin Orthod*, 26:661-664.

173. Jones G, Buschang PH, Kim KB, Oliver DR. (2008). Class II non-extraction patients treated with the Forsus Fatigue Resistant Device versus intermaxillary elastics. *Angle Orthod*, 78: 332-338.

174. Justus R. (2008). Are there any advantages of early Class II treatment? *Am J Orthod Dentofacial Orthop,* 134:717-8

175. Karacay S, Akin E, Olmez H, Gurton AU, Sagdic D. (2006). Forsus Nitinol Flat Spring and Jasper Jumper corrections of Class II Division 1 malocclusions. *Angle Orthod,* 76:666–672.

176. Kasai K. (1998). Soft tissue adaptability to hard tissues in facial profiles. *Am J Orthod Dentofacial Orthop,* 113:674– 684.

177. Keles A, Sayinsu K. (2000). A new approach in maxillary molar distalization: Intraoral bodily molar distalizer. *Am J Orthod Dentofacial Orthop,* 117(1):39-48.

178. King GJ, Keeling SD, Hocevar RA, Wheeler TT. (1990). The timing of treatment for Class II malocclusions in children: A literature review. *Angle Orthod*, 60(2):87–97.

179. Kingsley NW. (1880). Treatise on Oral Deformities as a Branch of Mechanical Surgery. Appleton & Lange, New York.

180. Klein PL. (1957). An evaluation of cervical traction on maxilla and the upper first permanent molar. *Angle Orthod,* 27:61-8.

181. Komposch G. (1982). Eine tierexperimentelle studie zur reaktionsfähigkeit der temporomandibulären strukturen auf kieferotthopädiche maβnahmen. *Fortschritte der Kieferorthopädie,* 43:407-431.

182. Konik M, Pancherz H, Hansen K. (1997). The mechanism of Class II correction in late Herbst treatment. *Am J Orthod Dentofacial Orthop,* 112:87-91

183. Koroluk LD, Tulloch JF, Phillips C. (2003). Incisor trauma and early treatment for Class II Division 1 malocclusion. *Am J Orthod Dentofacial Orthod,* 123:117-26.

184. Küçükkeleş N, Erverdi N. (1989). Herbst Apareyi ve Klinik Uygulamaları. *Türk Ortodonti Dergisi,* 2(2):351-356.

185. Küçükkeles N, İhan I, Orgun A. (2007). Treatment Efficiency in Skeletal Class II Patients Treated with the Jasper Jumper. A Cephalometric Evaluation. *Angle Orthod*, 77:449–456.

186. Lagerström LO, Nielsen L., Lee R, Isaacson RJ. (1990). Dental and skeletal contributions to occlusal correction in patients treated with the high-pull headgear–activator combination. *Am J Orthod Dentofacial Orthop,* 97:495-504.

187. Lai M, McNamara JA Jr. (1998). An evaluation of two phase treatment with the Herbst appliance and preadjusted edgewise therapy. *Semin Orthod,* 4:46–58.

188. Laine T, Hausen H. (1983). Occlusal anomalies in Finnish students related to age, sex, absent permanent teeth and orthodontic treatment. *Eur J Orthod*, 5: 125-13.

189. Lange DW, Kalra V, Broadbent HB, Powers M, Nelson S. (1995). Changes in soft tissue profile following treatment with the Bionator. *Angle Orthod,* 65:423–430.

190. Langford NM. Jr. (1982). Updating fabrication of the Herbst appliance. *J Clin Orthod*, 16:173-174.

191. Larsson E, Rönnerman A. (1981). Mandibular dysfunction symptoms in orthodontically treated patients ten years after the completion of treatment. *Eur J Orthod*, 3: 89-94.

192. Lehman R, Romuli A, Bakker V. (1988). Five-year treatment result with a headgear-activator combination. *Eur J Orthod*, 10:309-318.

193. Leung DK, Hagg U. (2001). An electromyographic investigation of the first six months of bioprogressive mandibular advancement of the Herbst appliance in adolescents. *Angle Orthod,* 71:177-184.

194. Lewis AB, Roche AF. (1988). Late growth changes in the craniofacial skeleton. *Angle Orthod,* 58: 127–135.

195. Lindahl L, Hollender L. (1977). Condylar fractures of the mandible. II: A radiographic study of remodeling processes in the temporomandibular joint. *Int J Oral Surg,* 6:153-65.

196. Love RJ, Murray JM, Mamandras AH. (1990). Facial growth in males 16 to 20 years of age. *Am J Orthod Dentofacial Orthop*, 97(3):200-206.

197. Luder HU. (1981). Effects of activator treatment--evidence for the *occurrence* of two different types of reaction. *Eur J Orthod,* 3:205-22

198. Luder HU. (1982). Skeletal profile changes related to two patterns of activator effects. *Am J Orthod Dentofacial Orthop*, 81:390-6

199. Luecke PE, Johnston LE. (1992). The effect of maxillary first premolar extraction and incisor retraction on mandibular position: Testing the central dogma of "functional orthodontics". *Am J Orthod Dentofacial Orthop*, 101(1):4-12.

200. Lux CJ, Dücker B, Pritsch M, Komposch G, Niekusch U. (2009). Occlusal status and prevalence of occlusal malocclusion traits among 9-year-old schoolchildren. *Eur J Orthod*, 31: 294 – 299.

201. Malmgren O, Omblus J, Hagg U, Pancherz H. (1987). Treatment with an appliance system in relation to treatment intensity and growth periods. *Am J Orthod Dentofacial Orthop*, 91:143-151

202. Mamandras AH, Allen LP. (1990). Mandibular response to orthodontic treatment with the Bionator appliance. *Am J Orthod Dentofacial Orthop,* 97:113–120.

203. Mao JJ, Wang X, Kopher RA. (2003). Biomechanics of craniofacial sutures: Orthopedic implications. *Angle Orthod,* 73:128-135.

204. Martin J, Pancherz H. (2009). Mandibular incisor position changes in relation to amount of bite jumping during Herbst/multibracket appliance treatment: A radiographic-cephalometric study. *Am J Orthod Dentofacial Orthop,* 136:44-51.

205. Massler M, Schour K. (1994). Postnatal growth pattern of the facial skeleton as measured by vital injections of alizarin red. *J Dent Res,* 23:218.

206. McNamara JA Jr. (1981). Components of Class II malocclusion in children 8–10 years of age. *Angle Orthod,* 51:177–202.

207. McNamara JA Jr. (1985). The role of functional appliance in contemporary orthodontics. In: *New vistas in orthodontics.* Ed: Johnston LE Jr, Lea & Febiger, Philadephia, p.38-75

208. McNamara JA Jr. (1988). Fabrication of the acrylic splint Herbst appliance. *Am J Orthod Dentofacial Orthop,* 94:10-18.

209. McNamara JA Jr, Bookstein FL, Shaughnessy TG. (1985). Skeletal and dental changes following functional regulator therapy on Class II patients. *Am J Orthod Dentofacial Orthop,* 88:91-110.

210. McNamara JA Jr, Brudon WL, Buckhardt DR, Huge SA. (2001). The Herbst appliance. In: *Orthodontics and dentofacial orthopedics.* Eds: McNamara JA Jr, Brudon WL. Ann Arbor: Needham Press, p.285-318.

211. McNamara JA Jr, Bryan FA. (1987). Long-term mandibular adaptations to protrusive function: An experimental study in Macaca mulatta. *Am J Orthod Dentofacial Orthop,* 92:98-108.

212. McNamara JA Jr, Howe RP, Dischinger TG. (1990). A comparison of the Herbst and Fränkel appliances in the treatment of Class II malocclusion. Am *J Orthod Dentofacial Orthop,* 98(2):134-144.

213. Mcsherry PF, Bradley H. (2000). Class II correction-Reducing patient compliance: A review of the available techniques. *J Orthod,* 27:219-225.

214. Melo ACM, dos Santos Pinto A, da Rosa Martins JC, Martins LP, Sakima MT. (2003). Orthopedic and orthodontic components of Class II Division 1 malocclusion correction with Balters bionator. *World J Orthod,* 4:237-42.

215. Melsen B. (1978). Effects of cervical anchorage during and after treatment: an implant study. *Am J Orthod Dentofacial Orthop,* 73:526-40.

216. Meral O, İşcan HN, Okay C, Gürsoy Y. (2004). Effects of bilateral upper first premolar extraction on the mandible. *Eur J Orthod,* 26:223-231.

217. Merwin D, Ngan P, Hagg U, Yiu C, Wei SHY. (1997). Timing for effective application of anteriorly directed orthopedic force to the maxilla. *Am J Orthod Dentofacial Orthop,* 112:292-9

218. Mills CM, McCulloch KJ. (1997). Case report: modified use of the Jasper Jumper appliance in a skeletal Class II mixed dentition case requiring palatal expansion. *Angle Orthod,* 4:277–282.

219. Moeller E. (1966). The chewing apparatus. An electromyographic study of the action of the muscles of mastication and its correlation to facial morphology. *Acta Physiol Scand*, 69:280.

220. Moro A, Janson G, Freitas MR, Henriques JC, Petrelli NE, Lauris JP. (2009). Class II Correction with the Cantilever Bite Jumper. *Angle Orthod,* 79:221-229.

221. Morris DO, Illing HM, Lee RT. (1998). A prospective evaluation of Bass, Bionator and Twin Block appliances. Part II—The soft tissues. *Eur J Orthod,* 20:663–684.

222. Moss ML. (1960). Functional analysis of human mandibular growth. *J Prosth Dent,* 10:1149.

223. Moss ML. (1962). The functional matrix. In: *Vistas in orthodontics*. Eds: Kraus GS, Riedel RP, p.85-98.

224. Moss ML, Rankow R. (1968). The role of the functional matrix in mandibular growth. *Angle Orthod,* 38:95.

225. Moss ML, Salentijn L. (1969). The primary role of functional matrices in facial growth. *Am J Orthod Dentofacial Orthop*, 55:566

226. Moyers RE, Riolo ML, Guire KE, Wainright RL, Bookstein FL. (1980). Differential diagnosis of Class II malocclusions: Part 1. Facial types associated with Class II malocclusions. *Am J Orthod Dentofacial Orthop,* 78:477-494.

227. Nakasima A, Ichinose M, Nakata S, Takahama Y. (1982). Hereditary factors in the craniofacial morphology of Angle's Class II and Class III malocclusions. *Am J Orthod Dentofacial Orthop,* 82(2):150-156.

228. Nakata N, Yu PI, Davis B, Nance WE. (1973). The use of genetic data in the prediction of craniofacial dimensions. *Am J Orthod Dentofacial Orthop,* 63:471-80.

229. Nalbantgil D, Arun T, Sayınsu K, Işık F. (2005). Skeletal, dental and soft tissue changes induced by the Jasper Jumper appliance in late adolescence. *Angle Orthod*, 75:426-436

230. Nanda RS. (1955). The rates of the growth of several facial components measured from serial cephalometric roentgenograms. *Am J Orthod Dentofacial Orthop,* 41:658-673.

231. Nanda RS. (1971). Growth changes in skeletal-facial profile and their significance in orthodontic diagnosis. *Am J Orthod Dentofacial Orthop,* 5:501-13.

232. Nanda RS, Ghosh J. (1995). Longitudinal growth changes in the sagittal relationship of maxilla and mandible. *Am J Orthod Dentofacial Orthop*, 107:79-90.

233. Nelson C, Harkness M, Herbison P. (1993). Mandibular changes during functional appliance treatment. *Am J Orthod Dentofacial Orthop*, 104:153-61.

234. Nelson B, Hansen K, Hagg U. (2000). Class II correction in patients treated with class II elastics and with fixed functional appliances: A comparative study. *Am J Orthod Dentofacial Orthop,* 118:142-149

235. Nelson B, Hagg U, Hansen K, Bendeus M. (2007). A long-term follow-up study of Class II malocclusion correction after treatment with Class II elastics or fixed functional appliances. *Am J Orthod Dentofacial Orthop,* 132:499-503.

236. Ngan PW, Byeczek E, Scheick J. (1997). Longitudinal evaluation of growth changes in Class II Division 1 subjects. *Semin Orthod*, 3(4):222-231

237. Ngan P, Hägg U, Yiu C, Merwin D, Wei SHY. (1998). Soft tissue and dentoskeletal profile changes associated with maxillary expansion and protraction headgear treatment. *Am J Orthod Dentofacial Orthop*, 109: 38-49.

238. Nguyen QV, Bezemer PD, Habets L, Prahl-Andersen B. (1999). A systematic review of the relationship between overjet size and traumatic dental injuries. *Eur J Orthod,* 21:503-15.

239. Nie Q, Lin J. (2006). A comparison of dental arch forms between Class II Division 1 and normal occlusion assessed by euclidean distance matrix analysis. *Am J Orthod Dentofacial Orthop,* 129(4):528-535.

240. O'Brien K, Wright J, Conboy F, Appelbe P, Davies L, Connolly I, Mitchell L, Littlewood S, Mandall N, Lewis D, Sandler J, Hammond M, Chadwick S, O'Neill J, McDade C, Oskouei M, Thiruvenkatachari B, Read M, Robinson S, Birnie D, Murray A, Shaw I, Harradine N, Worthington H. (2009). Early treatment for Class II malocclusion results in improved perceived facial profile. *Am J Orthod Dentofacial Orthop*, 135(5):573-579.

241. Ochoa BK, Nanda RS. (2004). Comparison of maxillary and mandibular growth. *Am J Orthod Dentofacial Orthop, 125*(2):148-159.

242. Omblus J, Malmgren O, Pancherz H, Hagg U, Hansen K. (1997). Long-term effects of Class II correction in Herbst and Bass therapy. *Eur J Orthod,* 19:185-193

243. Orgun A. (1995). İskeletsel Sınıf II Olgularda Jasper Jumper Apareyinin Tedavi Etkinliğinin Sefalometrik Araştırması. Marmara Üniversitesi Sağlık Bilimleri Enstitüsü, Doktora Tezi, İstanbul, (Danışman: Prof. Dr. N Küçükkeleş)

244. Pancherz H. (1979). Treatment of Class II malocclusions by jumping the bite with the Herbst appliance. *Am J Orthod Dentofacial Orthop*, 76:423-42.

245. Pancherz H. (1980). Activity of the temporal and masseter muscles in Class II, Division 1 malocclusions: An electromyographic investigation. *Am J Orthod Dentofacial Orthop,* 77:679-688.

246. Pancherz H. (1981). The effect of continuous bite jumping on the dentofacial complex: A follow-up study after Herbst appliance treatment of Class II malocclusions. *Eur J Orthod,* 3:49-60.

247. Pancherz H. (1982). The mechanism of Class II correction in Herbst appliance treatment: A cephalometric investigation. *Am J Orthod Dentofacial Orthop,* 82:104-113.

248. Pancherz H. (1984). A cephalometric analysis of skeletal and dental changes contributing to class II correction in activator treatment. *Am J Orthod Dentofacial Orthop,* 85:125–134.

249. Pancherz H. (1985). The Herbst appliance — Its biologic effects and clinical use. *Am J Orthod Dentofacial Orthop*, 87:1-20

250. Pancherz H. (1991). The nature of Class II relapse after Herbst appliance treatment: A cephalometric long-term investigation. *Am J Orthod Dentofacial Orthop*, 100:220-33.

251. Pancherz H. (1997). The effects, limitations, and long term dentofacial adaptations to treatment with the Herbst appliance. *Semin Orthod*, 4:232-243.

252. Pancherz H. (1997). The modern Herbst appliance. In: *Dentofacial orthopedics with functional appliances*. Eds: Graber TM, Rakosi T, Petrovic AG, 2nd ed, St Louis, Mosby-Year Book. p. 336-366.

253. Pancherz H. (2000). Dentofacial orthopedics or orthognathic surgery: Is it a matter of age? *Am J Orthod Dentofacial Orthop,* 117: 571-574.

254. Pancherz H. (2003). History, background, and development of the Herbst appliance. *Semin Orthod*, 9: 3-11.

255. Pancherz H, Anehus- Pancherz M. (1980). Muscle activity in Class II, Division 1 malocclusions treated by bite jumping with the Herbst appliance. *Am J Orthod Dentofacial Orthop,* 78:321-329.

256. Pancherz H, Anehus-Pancherz M. (1982). The effect of continuous bite jumping with the Herbst appliance on the masticatory system: A functional analysis of treated Class II malocclusions. *Eur J Orthod,* 4:37-44.

257. Pancherz H, Anehus-Pancherz M. (1993). The headgear effect of the Herbst appliance: A cephalometric long-term study. *Am J Orthod Dentofacial Orthop,* 103:510-520.

258. Pancherz H, Anehus-Pancherz M. (1994). Facial profile changes during and after Herbst appliance treatment. *Eur J Orthod,* 16:275-286.

259. Pancherz H, Hagg U. (1985). Dentofacial orthopedics in relation to somatic maturation. An analysis of 70 consecutive cases treated with the Herbst appliance. *Am J Orthod Dentofacial Orthop,* 88:273-287.

260. Pancherz H, Hansen K. (1986). Occlusal changes during and after Herbst treatment. *Eur J Orthod,* 8:215-28.

261. Pancherz H, Hansen K. (1988). Mandibular anchorage in Herbst treatment. *Eur J Orthod,* 10:149-64.

262. Pancherz H, Littmann C. (1989). Morphologie und lage des unterkiefers bei der Herbst-behandlung eine kephalometrische analyse der veranderungen bis zum wachstumabschlufl. *Inf Orthod Kieferorthop*, 21:493-513.

263. Pancherz H, Michailidou C. (2004). Temporomandibular joint growth changes in hyperdivergent and hypodivergent Herbst subjects. A long-term roentgenographic cephalometric study. *Am J Orthod Dentofacial Orthop,* 126:153-61

264. Pancherz H, Ruf S, Kohlhas P. (1998). "Effective condylar growth" and chin position changes in Herbst treatment. A cephalometric roentgenographic long-term study. *Am J Orthod Dentofacial Orthop*, 114:437-46.

265. Pancherz H, Ruf S, Thomalske-Faubert C. (1999). Mandibular articular disk position changes during Herbst treatment: a prospective longitudinal MRI study. *Am J Orthod Dentofacial Orthop,* 116:207–214

266. Pancherz H, Zieber K, Hoyer B. (1997). Cephalometric characteristics of Class II Division 1 and Class II Division 2 malocclusions: A comparative study in children. *Angle Orthod,* 67(2):111–120

267. Pangrazio-Kulbersh V, Berger JL, Chermak DS, Kaczynski R, Simon ES, Haerian A. (2003). Treatment effects of the mandibular anterior repositioning appliance on patients with Class II malocclusion. *Am J Orthod Dentofacial Orthop,* 123:286–295.

268. Papadopoulos MA. (2006). Orthodontic Treatment of the Class II Noncompliant Patient. In: Orthodontics: Current Principles and Techniques, Ed: Papadopoulos MA, Mosby, p.9, 69-78, 107, 182.

269. Papadopoulos MA. (2006). Orthodontic Treatment of the Class II Noncompliant Patient. In: The Ritto Appliance® - an easy way to treat Class II malocclusions. Ed: Ritto AK, Mosby, p.69-91.

270. Papadopoulos MA. (2006). Orthodontic Treatment of the Class II Noncompliant Patient. In: *The Mandibular Protraction Appliance in the treatment of noncompliant Class II patients.* Eds: Coelho Filho CM, Coelho FO, Mosby, p.93-104.

271. Papadopoulos MA. (2006). Orthodontic Treatment of the Class II Noncompliant Patient. In: *The Mandibular Anterior Repositioning Appliance.* Ed: Eckhart JE. Mosby, p.107-119.

272. Papadopoulos MA. (2006). Orthodontic Treatment of the Class II Noncompliant Patient. In: *The Jasper Jumper™.* Ed: Weiland FJ, Mosby, p.142.

273. Papadopoulos MA. (2006). Orthodontic Treatment of the Class II Noncompliant Patient. In: *The Eureka Spring™: A compact, versatile, and cost-effective Class II corrector.* Ed: DeVincenzo JP, Mosby, p.163-179.

274. Papadopoulos MA. (2006). Orthodontic Treatment of the Class II Noncompliant Patient. In: *The Twin Force Bite Corrector in the correction of Class II malocclusion in adolescent patients.* Eds: Uribe F, Rothenberg J, Nanda R, Mosby, p.181-201.

275. Paquette DE, Beattie JR, Johnston LE. (1992). A long-term comparison of nonextraction and premolar extraction edgewise therapy in 'borderline' Class II patients. *Am J Orthod Dentofacial Orthop*, 102:1-14.

276. Paulsen HU. (1997). Morphological changes of the TMJ condyles of 100 patients treated with the Herbst appliance in the period of puberty to adulthood: A long-term radiographic study. *Eur J Orthod,* 19:657-668.

277. Paulsen HU, Karle A. (2000). A computer tomographic and radiographic changes in the temporomandibular joints of two young adults with occlusal asymmetry, treated with the Herbst appliance. *Eur J Orthod,* 22:649-656.

278. Paulsen HU, Karle A, Bakke M, Herskind A. (1995). CT scanning and radiographic analysis of temporomandibular joints and cephalometric analysis in a case of Herbst treatment in late puberty. *Eur J Orthod,* 17:167-175.

279. Paulsen HU, Thomsen JS, Hougen HP, Moskilde L. (1999). A histomorphometric and scanning microscopy study of human condylar cartilage and bone tissue changes in relation to age. *Clin Orthod Res,* 2:67-78.

280. Pearson LE. (1978). Vertical control in treatment of patients having backward-rotational growth tendencies. *Angle Orthod*, 48:132-140.

281. Peltola JS, Könönen M, Nyström M. (1995). Radiographic characteristics in mandibular condyles of orthodontic patients before treatment. *Eur J Orthod,* 17: 69 - 77.

282. Perillo L, Johnston LE Jr, Ferro A. (1996). Permanence of skeletal changes after function regulator (FR-2) treatment of patients with retrusive Class II malocclusions. *Am J Orthod Dentofacial Orthop,* 109:132-9

283. Perillo L, Masucci C, Ferro F, Apicella D, Baccetti T. (2010). Prevalence of orthodontic treatment need in southern Italian schoolchildren. *Eur J Orthod,* 32:49-53.

284. Petrovic A. (1974). Control of postnatal growth of secondary cartilages of the mandible by mechanisms regulating occlusion. Cybernetic model. *Trans Eur Orth Soc,* 69-74.

285. Petrovic AG. (1986). A cybernetic approach to craniofacial growth control mechanisms. *Nova Acta Leopold,* 58:27–67

286. Petrovic AG, Stutzmann JJ. (1986). The concept of mandibular tissue- level growth potential and the responsiveness to a functional appliance. In: *Orthodontics: State of the Art, Essence of the Science.* Ed: Graber WL, St. Louis, Mosby, p.59–74.,

287. Petrovic A, Stutzman J, Lavergne J. (1990). Mechanism of craniofacial growth and modus operandi of functional appliances: A cell-level and cybernetic approach to orthodontic decision. In: Craniofacial growth theory and orthodontic treatment. Ed: Carlson DS, *Craniofacial Growth Series*, vol. 23. Ann Arbor: Center For Human Growth and Development, University of Michigan.

288. Petrovic AG, Stutzmann JJ, Oudet CL. (1975). Control processes in the postnatal growth of the condylar cartilage in the mandible. In: Determinants of mandibular form and growth. Monograph 5. *Craniofacial growth series.* Ed: McNamara JA Jr. Ann Arbor: Center for Human Growth and Development, University of Michigan.

289. Pollard LE, Mamandras AH. (1995). Male postpubertal facial growth in Class II malocclusions. *Am J Orthod Dentofacial Orthop*, 108(1):62-68.

290. Popowich K, Nebbe B, Major PW. (2003). Effect of Herbst treatment on mandibular temporomandiular joint morphology: A systematic literature review. *Am J Orthod Dentofacial Orthop,* 123:388-394.

291. Poulton DR. (1967). The influence of extraoral traction. *Am J Orthod Dentofacial Orthop,* 53:8-18.

292. Proffit WR. (1994). Forty-year review of extraction frequencies at a university orthodontic clinic. *Angle Orthod*, 64(6):407-414.

293. Proffit WR, Fields HW Jr. (2000). Contemporary Orthodontics. 3rd ed, St Louis, Mosby.

294. Proffit WR, Fields HW Jr. (2000). Contemporary Orthodontics. 3rd ed, St Louis, Mosby, p.4.

295. Proffit WR, Fields HW Jr. (2000). Contemporary Orthodontics. 3rd ed, St Louis, Mosby, p.276-278.

296. Proffit WR, Fields HW Jr. (2007). Contemporary Orthodontics. 4th ed, St Louis, Mosby, Philadelphia, p.44, p.113, p.306, p.352-367.

297. Proffit WR, Fields HW Jr. (2007). Contemporary Orthodontics. 4th ed, St Louis, Mosby, Philadelphia, p.352-367.

298. Proffit WR, Fields HW Jr, Moray LJ. (1998). Prevalence of malocclusion and orthodontic treatment need in the United States: Estimates from the NHANES III survey. *Int J Adult Orthodon Orthognath Surg*; 3:97–106.

299. Proffit W, Tulloch JFC. (2002). Preadolescent Class II problems: Treat now or wait? *Am J Orthod Dentofacial Orthop,* 121(6):560-562.

300. Pullinger AG, Solberg W, Hollender L, Petersson A. (1987). Relationship of mandibular condylar position to dental occlusion factors in an asymptomatic population. *Am J Orthod Dentofacial Orthop,* 91(3):200-206.

301. Rains MD, Nanda R. (1982). Soft tissue changes associated with maxillary incisor retraction. *Am J Orthod Dentofacial Orthop*, 81:481–488.

302. Rees LA. (1954). Structure and function of the mandibular joint. *Br Dent J,* 96:125-33.

303. Ricketts RM. (1952). A study of changes in temporomandibular relations associated with the treatment of Class II malocclusion (Angle). 38(12):918-933.

304. Ritto AK. (1998). Aparelhos funcionais fixos–novidades para o proximo seculo. *Ortodontia,* 2:124-150.

305. Ritto AK. (1999). Fixed functional appliances–trends for the next century. *Func Orthod,* 16:122-135.

306. Robin P. (1902). Demonstration pratique sur la costuction et la mise en bouche d'un nouvel appareil de redressement. *Rev Stomatol,* 9:561-90.

307. Rosenblum RE. (1995). Class II malocclusion: mandibular retrusion or maxillary protrusion? *Angle Orthod,* 65(1):49–62.

308. Ross AP, Gaffey BJ, Quick AN. (2007). Breakages using a unilateral fixed functional appliance: A Case Report using the Forsus Fatigue Resistant Device. *Journal of Orthod,* 34:2-5.

309. Rothenberg J. (2004). A prospective clinical analysis of a push-type fixed intermaxillary Class II correction appliance with a stability analysis six months posttreatment. Farmington, University of Connecticut.

310. Rothenberg J, Campbell ES, Nanda R. (2004). Class II correction with the Twin Force Bite Corrector. *J Clin Orthod,* 38:232-240.

311. Rothstein T, Yoon-Tarlie C. (2000). Dental and facial skeletal characteristics and growth of males and females with Class II, Division 1 malocclusion between the ages of 10 and 14 (revisited)—Part I: Characteristics of size, form, and position. *Am J Orthod Dentofacial Orthop,* 117(3):320-332.

312. Roux W. (1895). Gessamelte Abhandlungen über Entwicklungsmechanik der Organismen. Leipzig, Engelmann.

313. Rudzki-Janson I, Noachtar R. (1998). Functional appliance therapy with the Bionator. *Semin Orthod,* 4:33–45.

314. Ruf S, Hansen K, Pancherz H. (1998). Does orthodontic proclination of lower incisors in children and adolescents cause gingival recession? *Am J Orthod Dentofacial Orthop,* 114:100-106

315. Ruf S, Pancherz H. (1996). The effect of Herbst appliance treatment on the mandibular plane angle: A cephalometric roentgenographic study. *Am J Orthod Dentofacial Orthop,* 110:225-229.

316. Ruf S, Pancherz H. (1997). The mechanism of Class II correction during Herbst therapy in relation to the vertical jaw base relationship: a cephalometric roentgenographic study. *Angle Orthod,* 67:271-276.

317. Ruf S, Pancherz H. (1998). Temporomandibular joint growth adaptation in Herbst treatment: a prospective magnetic resonance imaging and cephalometric roentgenographic study. *Eur J Orthod,* 20:375–388.

318. Ruf S, Pancherz H. (1998). Long-term TMJ effects of Herbst treatment: A clinical and MRI study. *Am J Orthod Dentofacial Orthop,* 114:475–483.

319. Ruf S, Pancherz H. (1999). Dentoskeletal effects and facial profile changes in young adults treated with the Herbst appliance. *Angle Orthod*, 69:239-246.

320. Ruf S, Pancherz H. (1999). Temporomandibular joint remodeling in adolescents and young adults during Herbst treatment: A prospective longitudinal magnetic resonance imaging and cephalometric radiographic investigation. *Am J Orthod Dentofacial Orthop,* 115:607–618.

321. Ruf S, Pancherz H. (2000). Does bite-jumping damage TMJ? A prospective longitudinal clinical and MRI study of Herbst patients. *Angle Orthod*, 70:183-199.

322. Ruf S, Pancherz H. (2004). Orthognathic surgery and dentofacial orthopedics in adult Class II Division 1 treatment: Mandibular sagittal split osteotomy versus Herbst appliance. *Am J Orthod Dentofacial Orthop,* 126:140-152

323. Salzmann JA. (1968). Handicapping malocclusion assessment to establish treatment priority. *Am J Orthod Dentofacial Orthop,* 54:749-65.

324. Sarı Z, Uysal T, Karaman Aİ, Başçiftçi FA, Üşümez S, Demir A. (2003). Ortodontik malokluzyonlar ve tedavi seçeneklerinin değerlendirilmesi: Epidemiyolojik çalışma. *Türk Ortodonti Dergisi*, 16:119-126.

325. Sassouni V. (1969). A classification of skeletal facial types. *Am J Orthod Dentofacial Orthop,* 55:109-123.

326. Sassouni V, Nanda S. (1964). Analysis of dentofacial vertical proportions. *Am J Orthod Dentofacial Orthop,* 50:801-823.

327. Sato H, Fujii T, Uetani M, Kitamori H. (1997). Anterior mandibular repositioning in a patient with temporomandibular disorders: a clinical and tomographic follow-up case report. *J Craniomand Pract,* 15:84-8.

328. Saunders SR, Popovich F, Thompson GW. (1980). A family study of craniofacial dimensions in the Burlington Growth Centre sample. *Am J Orthod Dentofacial Orthop,* 78:394-403.

329. Sayın MÖ, Türkkahraman H. (2004). Malocclusion and crowding in an orthodontically referred Turkish population. *Angle Orthod,* 74(5):635–639.

330. Sayın MÖ, Türkkahraman H. (2005). Cephalometric evaluation of nongrowing females with skeletal and dental Class II, Division 1 malocclusion. *Angle Orthod*, 75:656–660.

331. Schaefer AT, McNamara JA Jr, Franchi L, Baccetti T. (2004). A cephalometric comparison of treatment with the Twin-block and stainless steel crown Herbst appliances followed by fixed appliance therapy. *Am J Orthod Dentofacial Orthop.* 126:7–15.

332. Schiavoni R, Grenga V, Macri V. (1992). Treatment of Class II high angle malocclusions with the Herbst appliance: A cephalometric investigation. *Am J Orthod Dentofacial Orthop*, 102(5):393-409

333. Schudy FF. (1964). Vertical growth versus anteroposterior growth as related to function and treatment. *Angle Orthod,* 34:75-93.

334. Schweitzer M, Pancherz H. (2001). The incisor-lip relationship in Herbst/multibracket appliance treatment of Class II, Division 2 malocclusions. *Angle Orthod,* 71:358-363

335. Schwindling FP. (1997ed). Jasper Jumper Color Atlas. Schwindling, Merzig, Germany.

336. Serbesis-Tsarudis C, Pancherz H. (2008). ''Effective'' TMJ and Chin Position Changes in Class II Treatment. *Angle Orthod,* 78:813-818.

337. Sessle BJ, Gurza SC. (1982). Jaw movement-related activity and reflexly induced changes in the lateral pterygoid muscle of the monkey Macaca fascicularis. *Arch Oral Biol,* 27:167-73.

338. Sessle BJ, Woodside DG, Bourque P, Gurza P, Powell S, Voudouris JC, Metaxas A, Altuna G. (1990). Effect of functional appliances on jaw muscle activity. *Am J Orthod Dentofacial Orthop*, 98:222-9.

339. Shaw W, Richmond S, Kingdon A, Kenealy P, Worthington H. (2007). A 20-year cohort study of health gain from orthodontic treatment: Psychological outcome. *Am J Orthod Dentofacial Orthop,* 132:146-57.

340. Sidhu MS, Kharbanda OP, Sidhu SS. (1995). Cephalometric analysis of changes produced by a modified Herbst appliance in the treatment of Class II Division 1 malocclusion. *Br J Orthod,* 22:1-12.

341. Silva RG, Kang DS. (2001). Prevalence of malocclusion among Latino adolescents. *Am J Orthod Dentofacial Orthop,* 119(3):313-315.

342. Silverstein A. (1954). Changes in the bony facial profile coincident with treatment of Class II, Division I malocclusion. *Angle Orthod,* 24:214-37.

343. Siqueira DF, Almeira RR, Janson G, Brandão AG, Coelho Filho CM. (2007) Dentoskeletal and soft-tissue changes with cervical headgear and mandibular protraction appliance therapy in the treatment of Class II malocclusions. *Am J Orthod Dentofacial Orthop,* 131:447.e21-447.e30

342. Smith RA. (1939). The etiology of Angle Class II Division I malocclusion. *Angle Orthod,* 9(1):15–19.

345. Smith JR. (1998). Matching the Herbst to the malocclusion. *Clin Impressions*, 7:6-12, 20-23.

346. Smith JR. (1999). Matching the Herbst to the malocclusion: Part II. *Clin Impressions,* 8:14-23.

347. Soh J, Sandham A, Chan YH. (2005). Occlusal status in Asian male adults. *Angle Orthod,* 75(5):814–820.

348. Solow B. (1980). The dentoalveolar compensatory mechanism: Background and clinical implications. *Br J Orthod,* 7:145-61.

349. Staley NR. (2001). Etiology and Prevalence of Malocclusion. In: Bishara SE. Textbook of Orthodontics. Saunders, Philadelphia, p.84-104.

350. Stromeyer EL, Caruso JM, DeVincenzo JP. (2002). A cephalometric study of the Class II Correction Effects of the Eureka Spring. *Angle Orthod,* 72:203–210.

351. Stucki N, Ingervall B. (1998). The use of the Jasper Jumper for the correction of Class II malocclusion in the young permanent dentition. *Eur J Orthod*, 20: 271-281.

352. Suzuki A, Takahama Y. (1988). A cephalometric study on the similarity of craniofacial morphology between children and their parents. *J Jpn Orthod Soc,* 47:697-719.

353. Suzuki A, Takahama Y. (1991). Parental data used to predict growth of craniofacial form. *Am J Orthod Dentofacial Orthop,* 99:107-21.

354. Şenocak M. (1990). Temel biyoistatistik. Çağlayan kitapevi, İstanbul, p.87-114,154-172.

355. Tadej G, Engstrom C, Borrman H, Christiansen EL. (1989). Mandibular condyle morphology in relation to malocclusions in children. *Angle Orthod,* 59(3):187–194.

356. Talass MF, Talass L, Baker RC. (1987). Soft tissue profile changes resulting from retraction of maxillary incisor. *Am J Orthod Dentofacial Orthop*, 91:385–394.

357. Tallgren A. (1967). The effect of denture wearing on facial morphology. A 7-year longitudinal study. *Acta Odont. Scand.,* 25:563-92.

358. Tang EL, Wei SH. (1993). Recording and measuring malocclusion: a review of the literature. *Am J Orthod Dentofacial Orthop,* 103:344-51.

359. Tausche E, Luck O, Harzer W. (2004). Prevalence of malocclusions in the early mixed dentition and orthodontic treatment need. *Eur J Orthod*, 26: 237 – 244.

360. Teuscher UM. (1978). A growth-related concept for skeletal Class II treatment. *Am J Orthod Dentofacial Orthop,* 74:258-75.

361. Teuscher UM. (1986). Appraisal of growth and reaction to extraoral anchorage. *Am J Orthod Dentofacial Orthop,* 89:113-21.

362. Thilander B, Pena L, Infante C, Parada SS, De Mayorga C. (2001). Prevalence of malocclusion and orthodontic treatment need in children and adolescents in Bogota, Colombia. An epidemiological study related to different stages of dental development. *Eur J Orthod*, 23: 153 - 168.

363. Tomlak DJ, Piecuch JF, Weinstein S. (1984). Morphologic analysis of upper lip area following maxillary osteotomy via the tunneling approach. *Am J Orthod Dentofacial Orthop*, 85:488–493.

364. Trenouth MJ. (2000). Cephalometric evaluation of the Twin Block appliance in the treatment of Class II Division 1 malocclusion with matched normative data. *Am J Orthod Dentofacial Orthop,* 117:54–5.

365. Tulloch JFC, Phillips C, Koch G, Proffit WR. (1997). The effect of early intervention on skeletal pattern in Class II malocclusion: A randomized clinical trial. *Am J Orthod Dentofacial Orthop*, 111:391-400.

366. Tung AW, Kiyak HA. (1998). Psychological influences on the timing of orthodontic treatment. *Am J Orthod Dentofacial Orthop,* 113:29–39.

367. Ugur T, Ciger S, Aksoy A, Telli A. (1998). An epidemiological survey using the Treatment Priority Index (TPI). *Eur J Orthod*, 20: 189 - 193.

368. Üçem TT, Yüksel S. (1998). Effects of different vectors of forces applied by combined headgear. *Am J Orthod Dentofacial Orthop,* 113(3):316-323.

369. Valant JR, Sinclair PM. (1989). Treatment effects of the Herbst appliance. *Am J Orthod Dentofacial Orthop,* 95:138-147.

370. Van Laecken R, Martin CA, Dischinger T, Razmus T, Ngan P. (2006). Treatment effects of the edgewise Herbst appliance: A cephalometric and tomographic investigation. *Am J Orthod Dentofacial Orthop,* 130:582-93.

371. Vargervik K, Harvold EP. (1985). Response to activator treatment in class II malocclusions. *Am J Orthod Dentofacial Orthop,* 88:242–251.

372. Vaughn GA, Mason B, Moon H-B, Turley PK. (2005). The effects of maxillary protraction therapy with or without rapid palatal expansion: A prospective, randomized clinical trial. *Am J Orthod Dentofacial Orthop,* 128:299-309.

373. Vitral RWF, Telles CS, Fraga MR, De Oliveira RSMF, Tanaka OM. (2004). Computed tomography evaluation of temporomandibular joint alterations in patients with Class II Division 1 subdivision malocclusions: Condyle-fossa relationship. *Am J Orthod Dentofacial Orthop,* 126(1):48-52.

374. Vogt W. (2006). The Forsus fatigue resistant device. *J Clin Orthod*, 40:368-377.

375. Von Bremen J, Pancherz H. (2002). Efficiency of early and late Class II Division 1 treatment. *Am J Orthod Dentofacial Orthop*, 121:31-7.

376. Voudouris JC, Kuftinec MM. (2000). Improved clinical use of Twin-block and Herbst as a result of radiating viscoelastic tissue forces on the condyle and fossa in treatment and long-term retention: Growth relativity. *Am J Orthod Dentofacial Orthop,* 117:247-266.

377. Voudouris JC, Woodside DG, Altuna G, Angelopoulos G, Bourque PJ, Lacouture CY. (2003). Condyle-fossa modifications and muscle interactions during Herbst treatment, part 1. New technological methods. *Am J Orthod Dentofacial Orthop*, 123:604-613.

378. Wahl N. (2006). Orthodontics in 3 millennia. Chapter 9: Functional appliances to midcentury. *Am J Orthod Dentofacial Orthop*, 129(6): 829-833.

379. Weiland FJ, Bantleon HP. (1995). Treatment of Class II malocclusions with the Jasper Jumper appliance — a preliminary report. *Am J Orthod Dentofacial Orthop*, 108:341-350.

380. Weiland FJ, Droschl H. (1996). Treatment of a Class II Division 1 malocclusion with the Jasper Jumper: A case report. *Am J Orthod Dentofacial Orthop,* 109:1-7.

381. Weschler D, Pancherz H. (2005). Efficiency of three mandibular anchorage forms in Herbst treatment: A cephalometric investigation. *Angle Orthod,* 75:23-27.

382. Wieslander L. (1974). The effect of force on the craniofacial development. *Am J Orthod Dentofacial Orthop,* 65:531-8.

383. Wieslander L. (1984). Intensive treatment of severe Class II malocclusions with a headgear-Herbst appliance in the early mixed dentition. *Am J Orthod Dentofacial Orthop*, 86:1-13.

384. Wieslander L. (1993). Long-term effects of treatment with the headgear-Herbst appliance in the early mixed dentition: Stability or relapse? *Am J Orthod Dentofacial Orthop,* 104:319-29.

385. Wieslander L, Lagerstrom L. (1979). The effect of activator treatment on class II malocclusions. *Am J Orthod Dentofacial Orthop,* 75:20–26.

386. Windmiller EC. (1993). The acrylic-splint Herbst appliance: A cephalometric evaluation. *Am J Orthod Dentofacial Orthop,* 104:73-84.

387. Woodside DG, Altuna G, Harvold E, Herbert M, Metaxas A. (1983). Primate experiments in malocclusion and bone induction. *Am J Orthod Dentofacial Orthop,* 83:460-8.

388. Woodside DG, Linder-Aronson, Lundström A, McWilliam J. (1991). Mandibular and maxillary growth after changed mode of breathing. *Am J Orthod Dentofacial Orthop,* 100(1):1-18.

389. Woodside DG, Metaxas A, Altuna G. (1987). The influence of functional appliance therapy on glenoid fossa remodeling. *Am J Orthod Dentofacial Orthop*, 92:98-108.

390. Wortham JR, Dolce C, McGorray SP, Le H, King GJ, Wheeler TT. (2009). Comparison of arch dimension changes in 1-phase vs 2-phase treatment of Class II malocclusion. *Am J Orthod Dentofacial Orthop,* 136:65-74.

391.Wyatt WE. (1987). Preventing adverse effects on the temporomandibular joint through orthodontic treatment. *Am J Orthod Dentofacial Orthop*, 91:493-499.

392. Yamaguchi K, Nanda RS. (1991). The effects of extraction and nonextraction treatment on the mandibular position. *Am J Orthod Dentofacial Orthop,* 100:443-452.

393. Yamin-Lacouture C, Woodside DG, Sektakof PA, Sessle BJ. (1997). The action of three types of functional appliances on the activity of masticatory muscles. *Am J Orthod Dentofacial Orthop,* 112:560–572.

10. BIOGRAPHY

I was born in Çanakkale, Türkiye in 10.02.1980. I completed my elementary school education in Çankaya Elementary school in 1988. I had my high school education in İbrahim Bodur High School and graduated in 1998. Completing my university education in Marmara University Faculty of Dentistry, I became a dentist in 2004. I joined PhD programme in Marmara University Faculty of Dentistry Department of Orthodontics in 2004.

MARMARA ÜNİVERSİTESİ TIP FAKÜLTESİ
ARAŞTIRMA ETİK KURULU

Sayı : B.30.2.MAR.0.01.02/AEK/396
Konu :

02.05.2008

Sayın Yrd.Doç.Dr. Toros ALCAN

MAR-YÇ-2008-0090 protokol nolu " Sınıf II bölüm I olgularda Forsus ™ Fatigue-Resistant Device aygıtının iskeletsel ve dentoalveolar etkilerinin incelenmesi " isimli projeniz Fakültemiz Araştırma Etik Kurulu tarafından incelenerek onaylanmıştır.

Prof. Dr. Haner DİRESKENELİ
Marmara üniversitesi Tıp Fakültesi
Araştırma Etik Kurul Başkanı